INTEGRATED MULTIBODY DYNAMICS AND FATIGUE MODELS FOR PREDICTING THE FATIGUE LIFE OF POLY–V RIBBED BELTS

A Thesis
Submitted to the Faculty
of
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by
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Requirements of the Degree
of
Masters of Science in Mechanical Engineering

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APPENDIX

APPENDIX: PARAMETER SENSITIVITY RESULTS

1 Tensioner Arm Viscous Damping Increases To 5 $N.m.sec/rad$ Instead Of 0 $N.m.sec/rad$

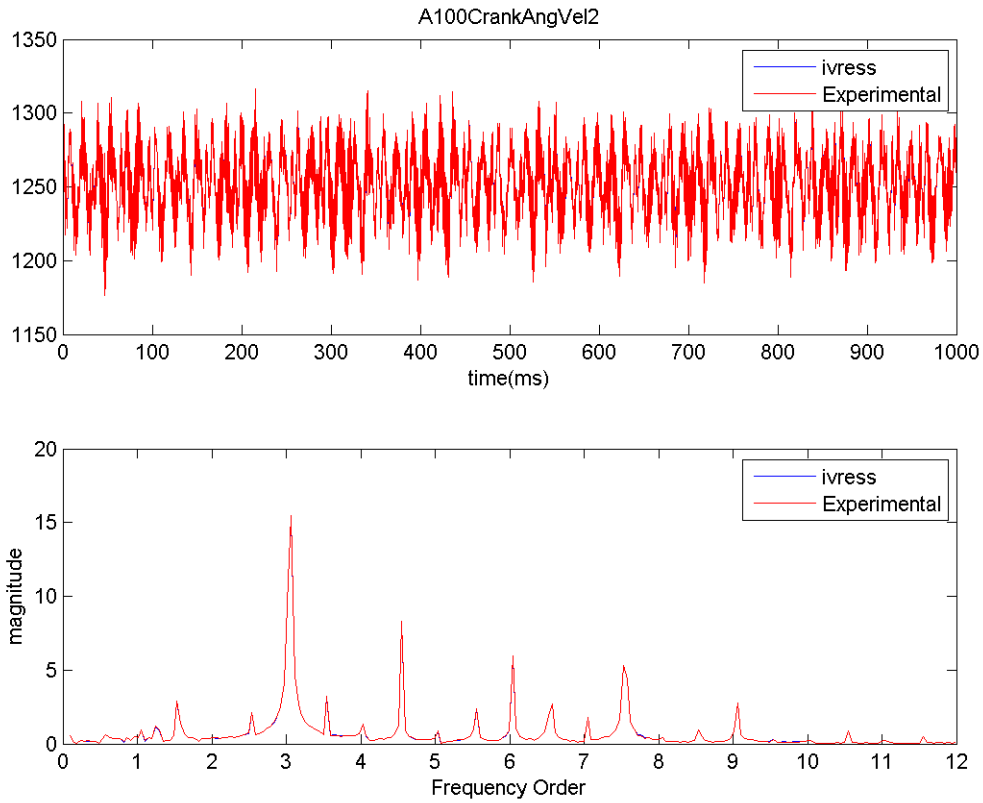

Figure 1 Crankshaft angular velocity in the A100 operation range with tensioner arm viscous damping = 5 $N.m.s/rad$ instead of 0 $N.m.s/rad$

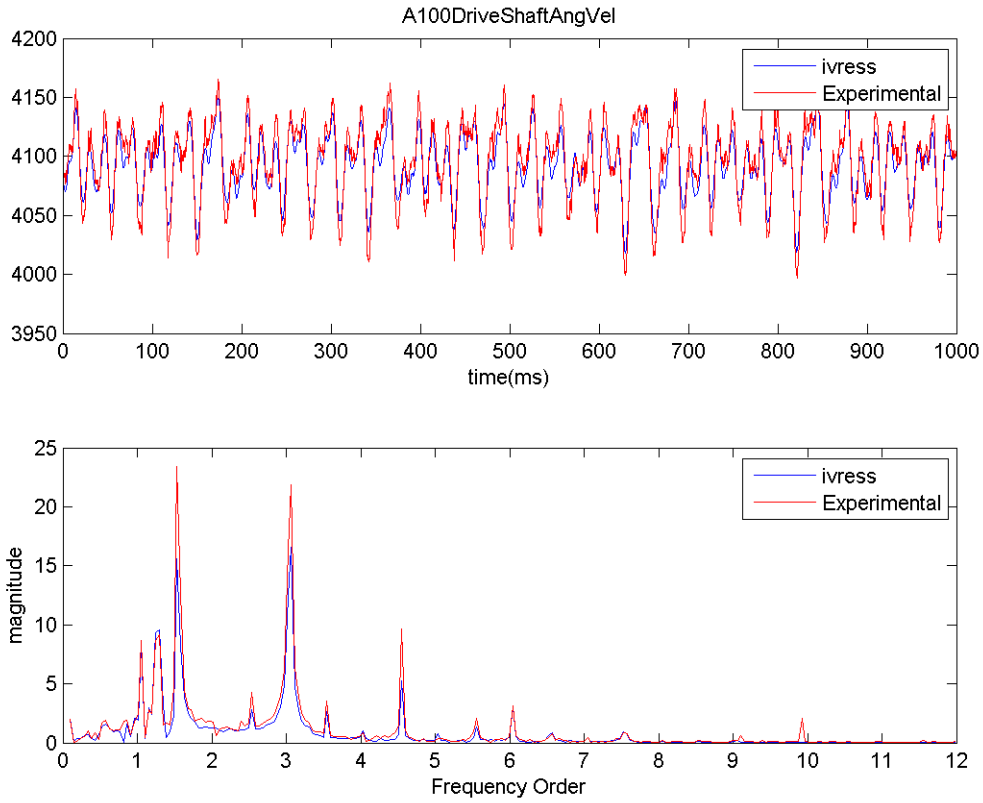

Figure 2 Drive haft angular velocity in the A100 operation range with tensioner arm viscous damping = 5 $N.m.s/rad$ instead of 0 $N.m.s/rad$

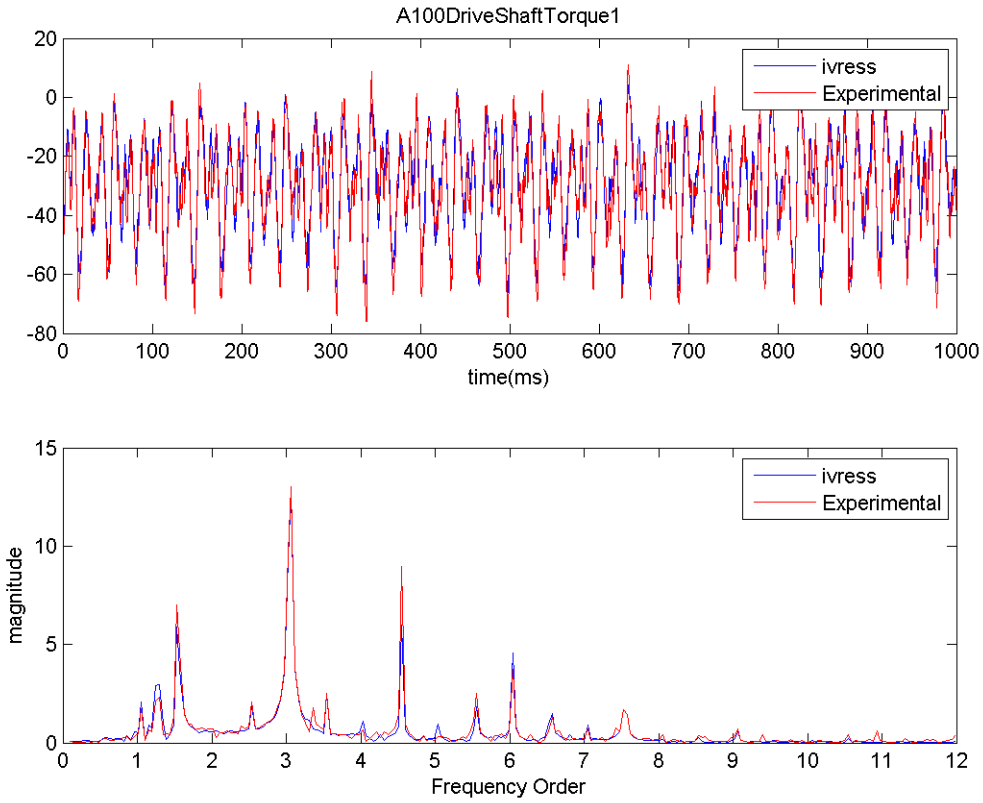

Figure 3 Drive haft torque in the A100 operation range with tensioner arm viscous damping = 5 $N.m.s/rad$ instead of 0 $N.m.s/rad$

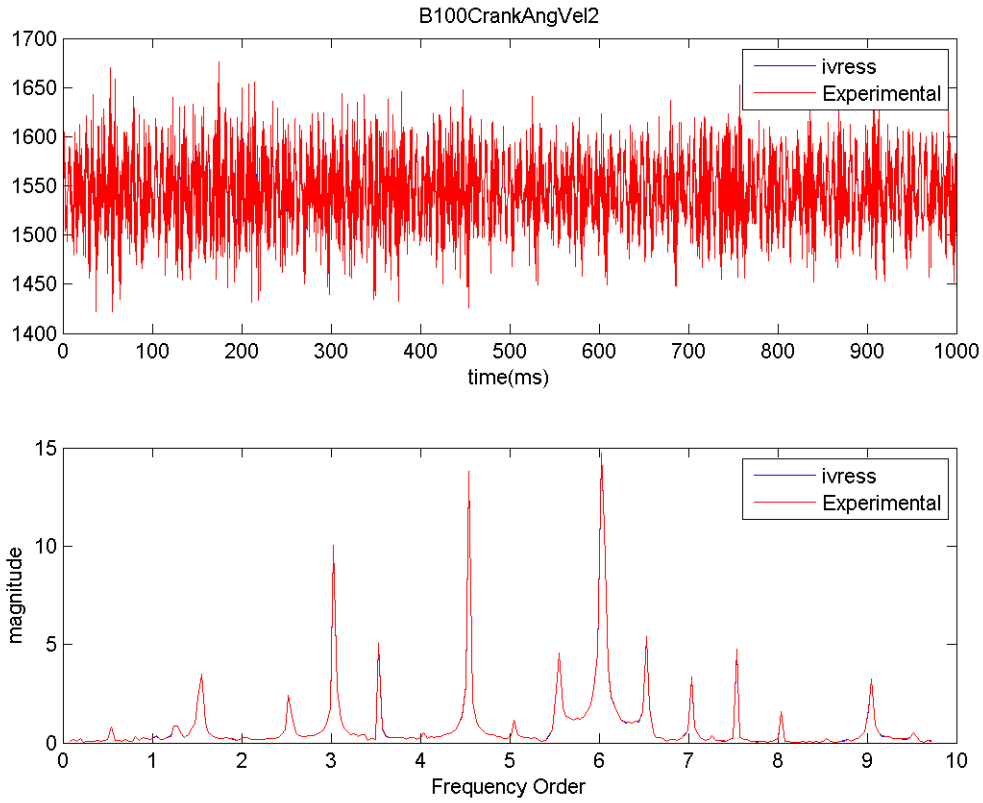

Figure 4 Crankshaft angular velocity in the B100 operation range with tensioner arm viscous damping = 5 $N.m.s/rad$ instead of 0 $N.m.s/rad$

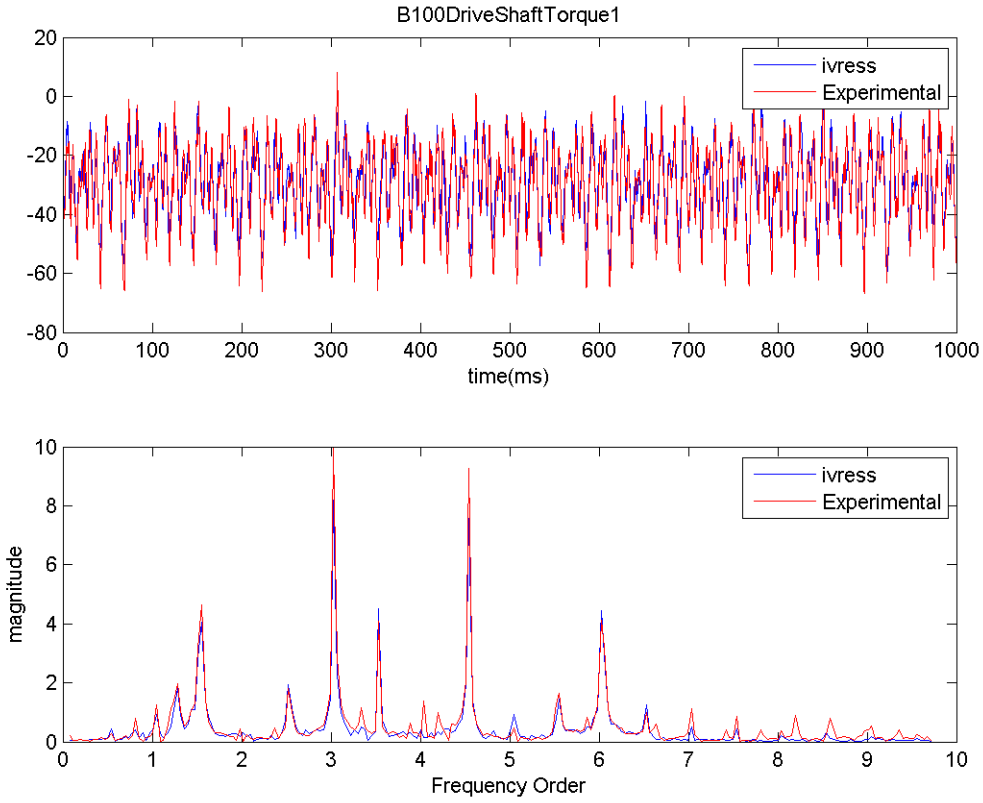

Figure 5 Drive haft torque in the B100 operation range with tensioner arm viscous damping = 5 $N.m.s/rad$ instead of 0 $N.m.s/rad$

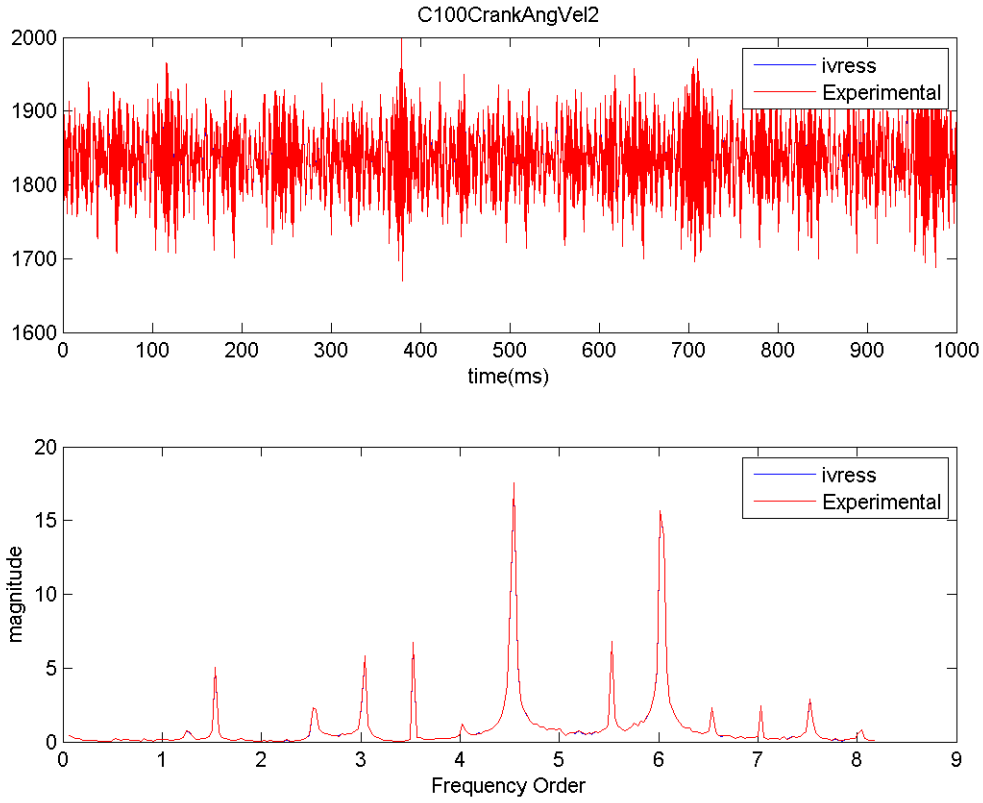

Figure 6 Crankshaft angular velocity in the C100 operation range with tensioner arm viscous damping = 5 $N.m.s/rad$ instead of 0 $N.m.s/rad$

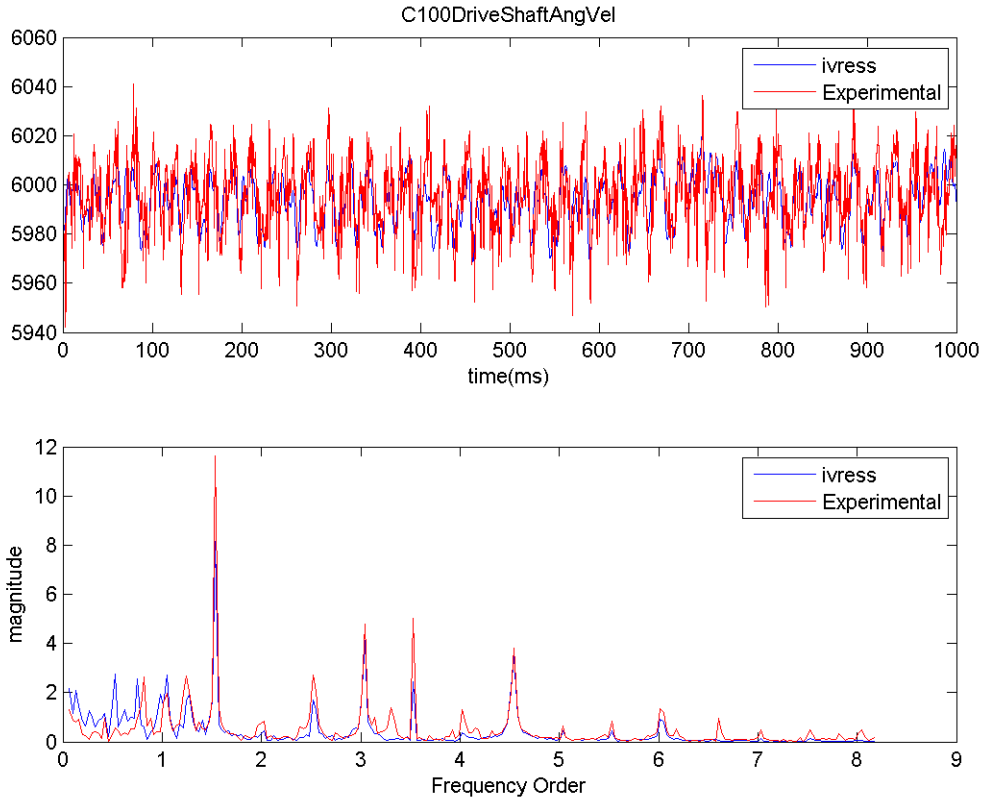

Figure 7 Drive haft angular velocity in the C100 operation range with tensioner arm viscous damping = 5 $N.m.s/rad$ instead of 0 $N.m.s/rad$

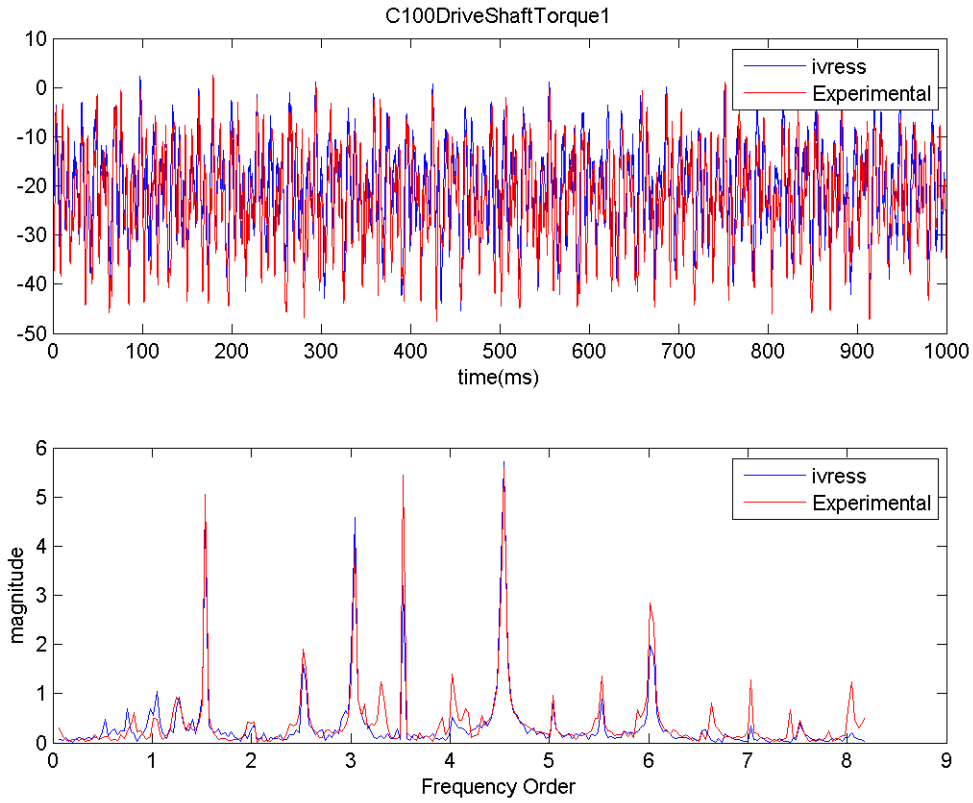

Figure 8 Drive haft torque in the C100 operation range with tensioner arm viscous damping = 5 $N.m.s/rad$ instead of 0 $N.m.s/rad$

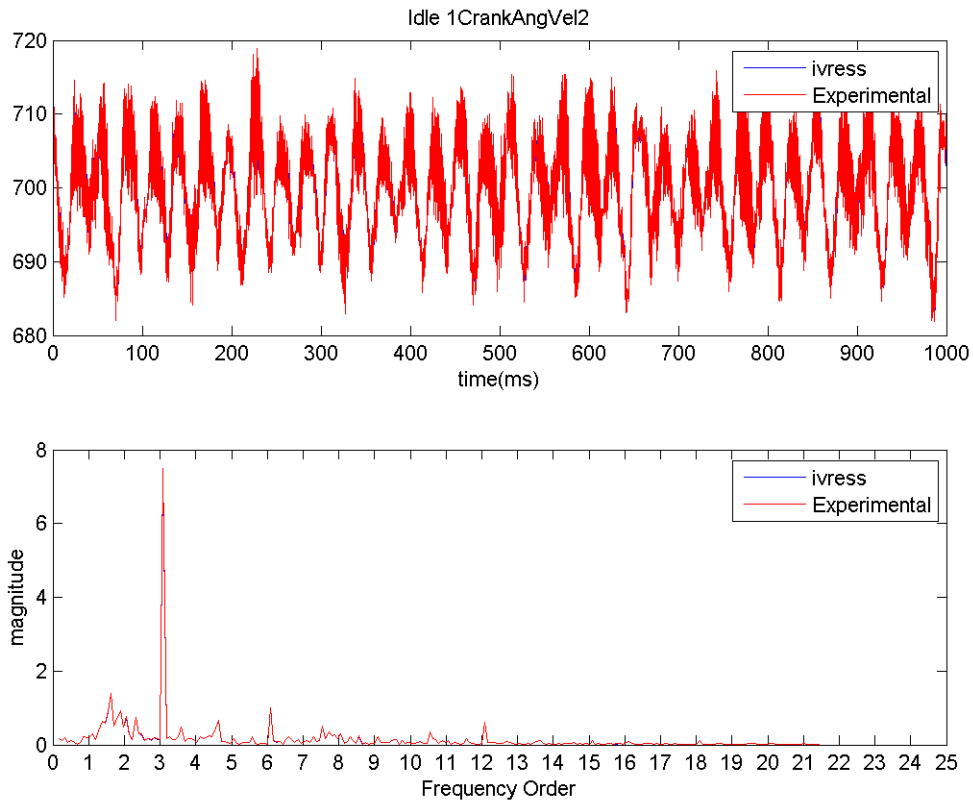

Figure 9 Crankshaft angular velocity in the idle operation range with tensioner arm viscous damping = 5 $N.m.s/rad$ instead of 0 $N.m.s/rad$

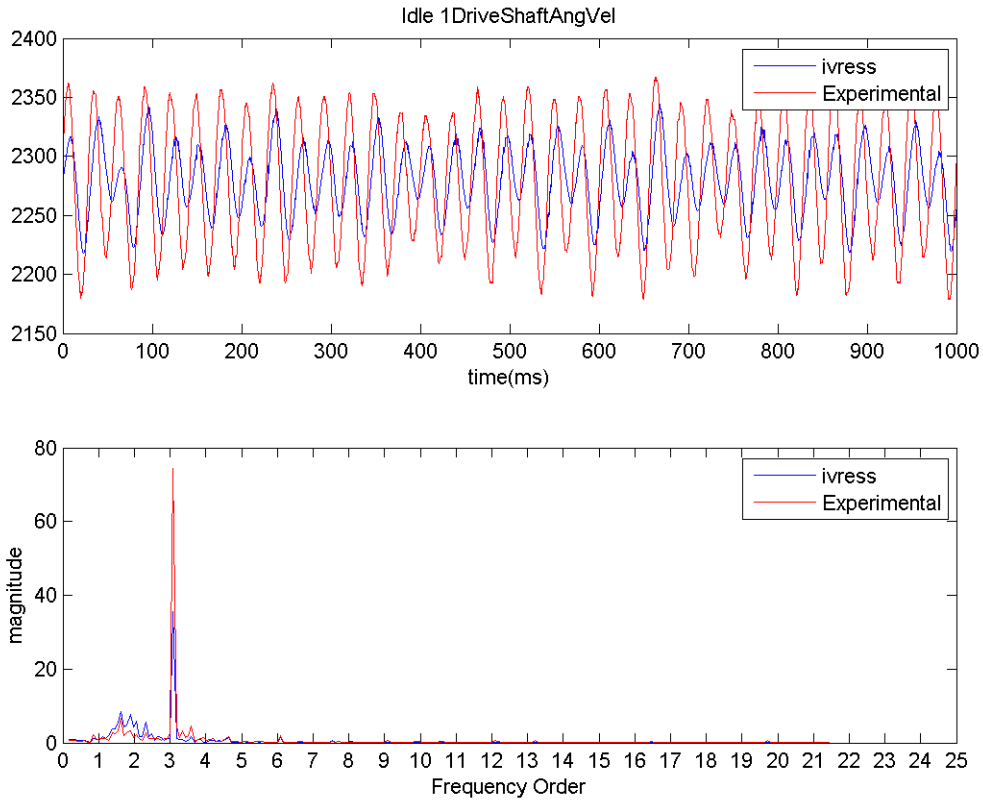

Figure 10 Drive haft angular velocity in the idle operation range with tensioner arm viscous damping = 5 $N.m.s/rad$ instead of 0 $N.m.s/rad$

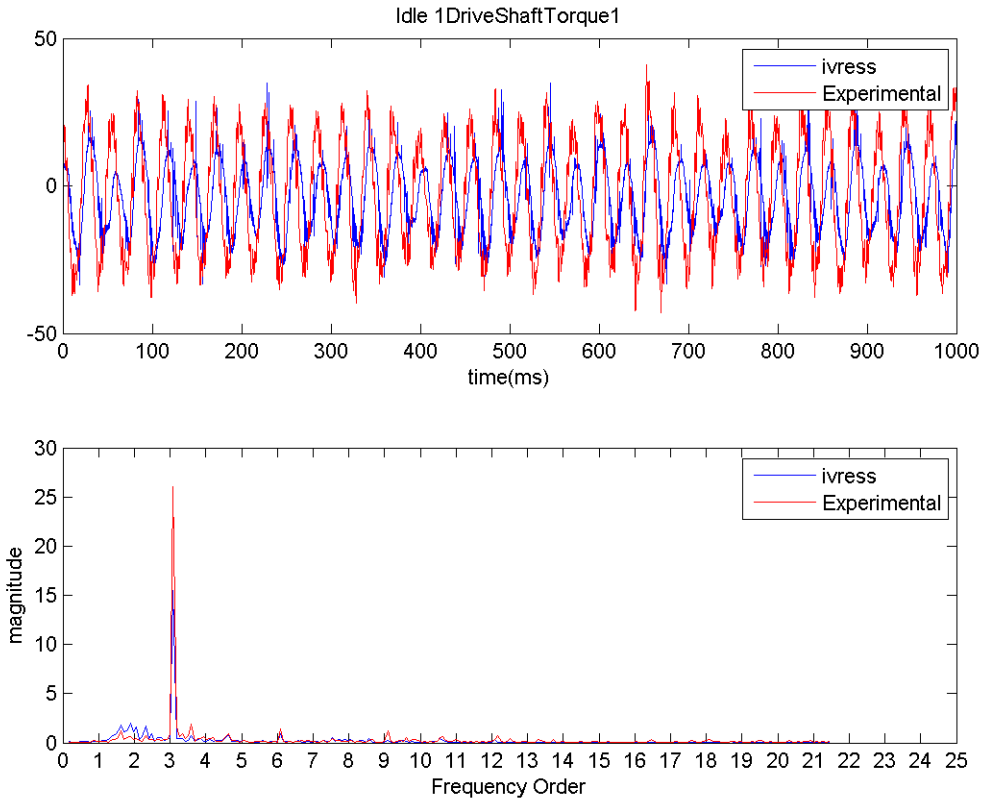

Figure 11 Drive haft torque in the idle operation range with tensioner arm viscous damping = 5 $N.m.s/rad$ instead of 0 $N.m.s/rad$

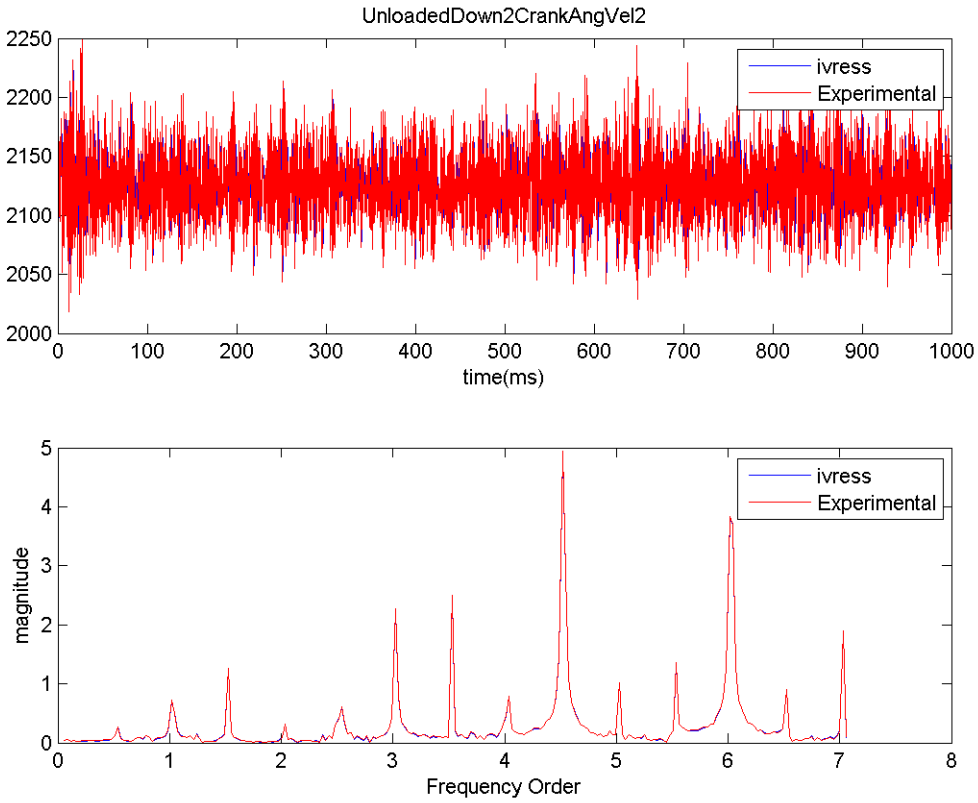

Figure 12 Crankshaft angular velocity in the UnloadedDown operation range with tensioner arm viscous damping = 5 $N.m.s/rad$ instead of 0 $N.m.s/rad$

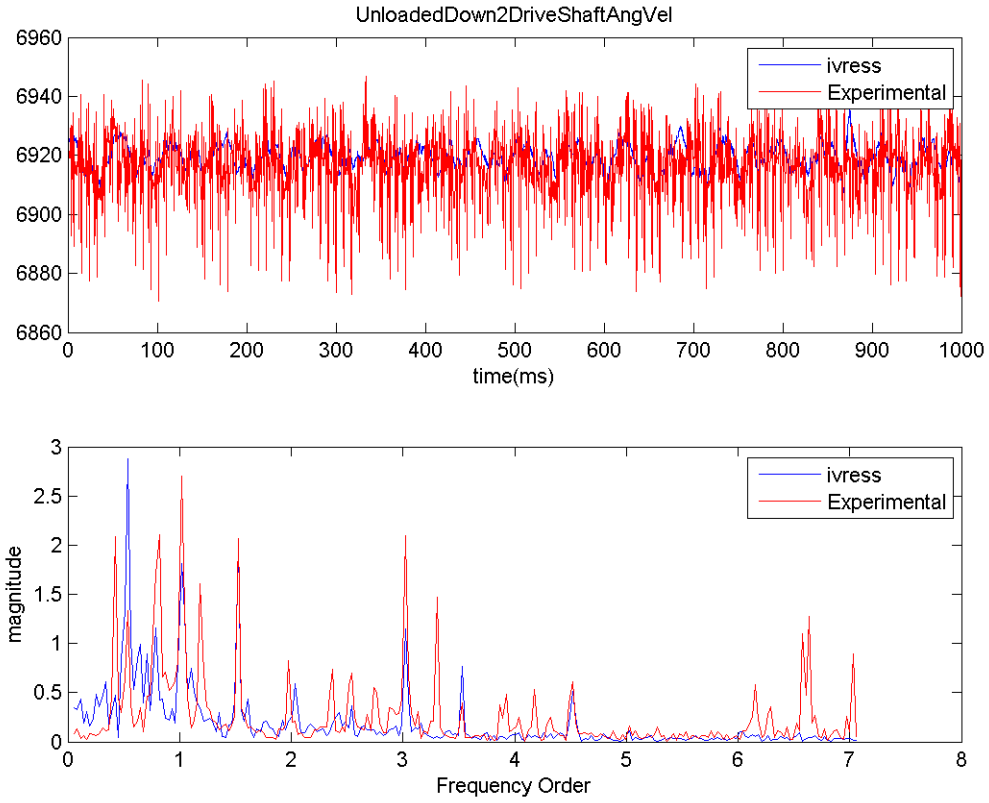

Figure 13 Drive haft angular velocity in the UnloadedDown operation range with tensioner arm viscous damping = 5 $N.m.s/rad$ instead of 0 $N.m.s/rad$

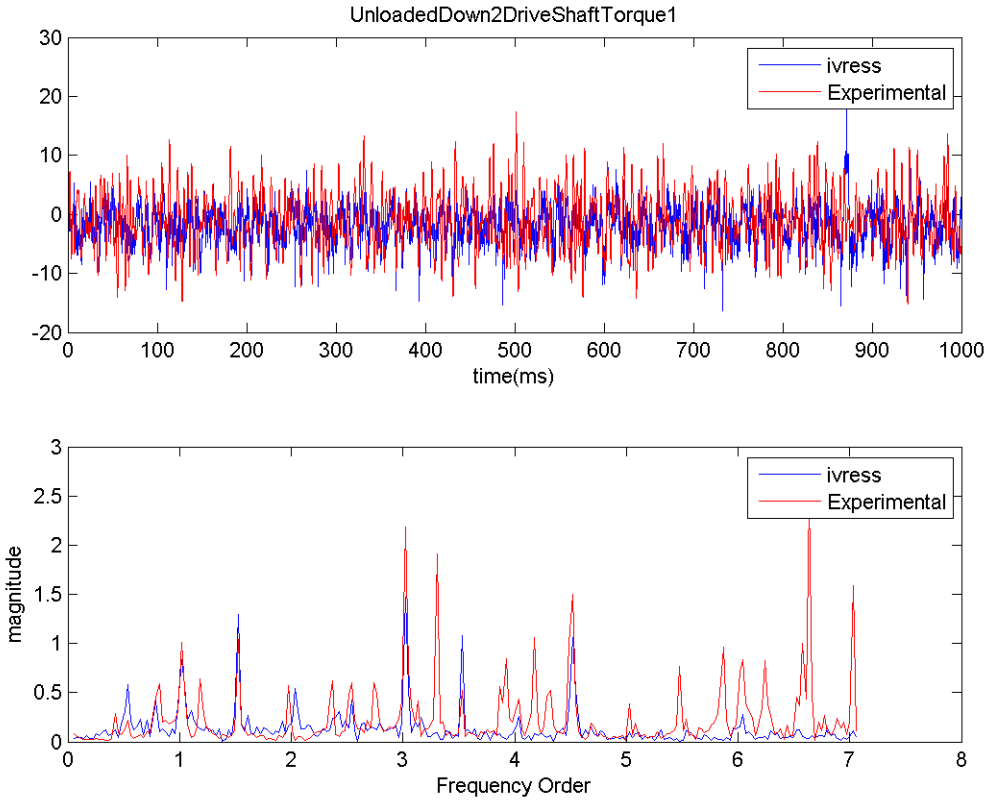

Figure 14 Drive haft torque in the UnloadedDown operation range with tensioner arm viscous damping = 5 $N.m.s/rad$ instead of 0 $N.m.s/rad$

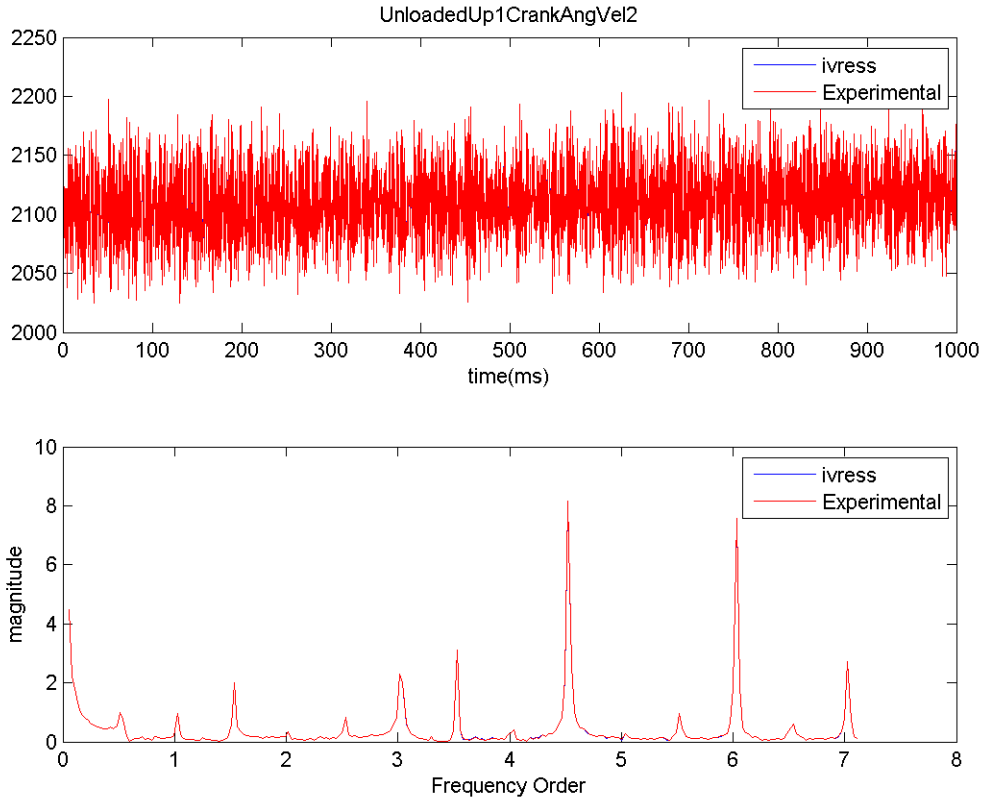

Figure 15 Crankshaft angular velocity in the UnloadedUp operation range with tensioner arm viscous damping = 5 $N.m.s/rad$ instead of 0 $N.m.s/rad$

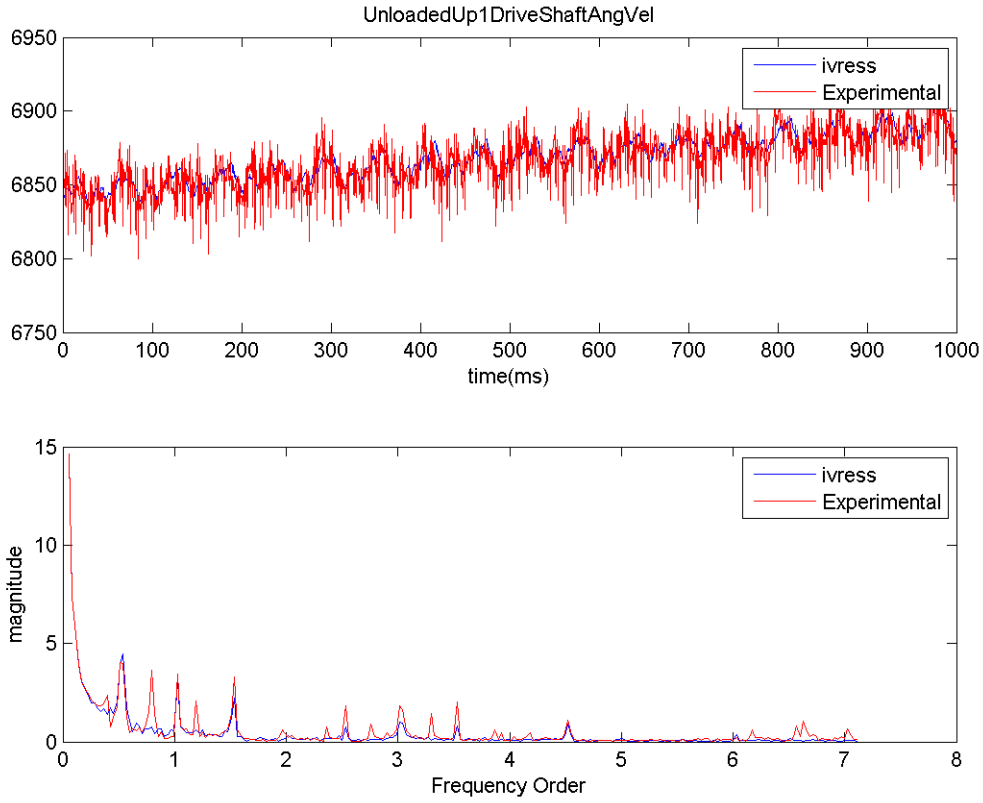

Figure 16 Drive haft angular velocity in the UnloadedUp operation range with tensioner arm viscous damping = 5 $N.m.s/rad$ instead of 0 $N.m.s/rad$

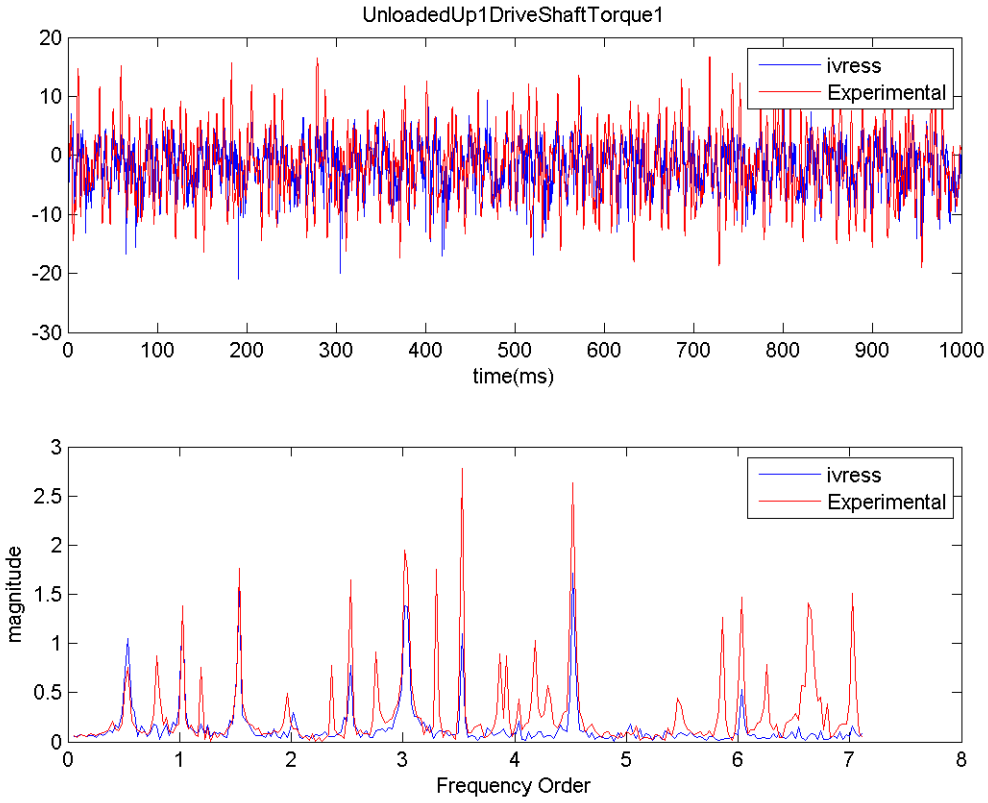

Figure 17 Drive haft torque in the UnloadedUp operation range with tensioner arm viscous damping = 5 $N.m.s/rad$ instead of 0 $N.m.s/rad$

2 Tensioner Arm Friction Moment Increases To 8 $N.m$ Instead Of 3.14 $N.m$

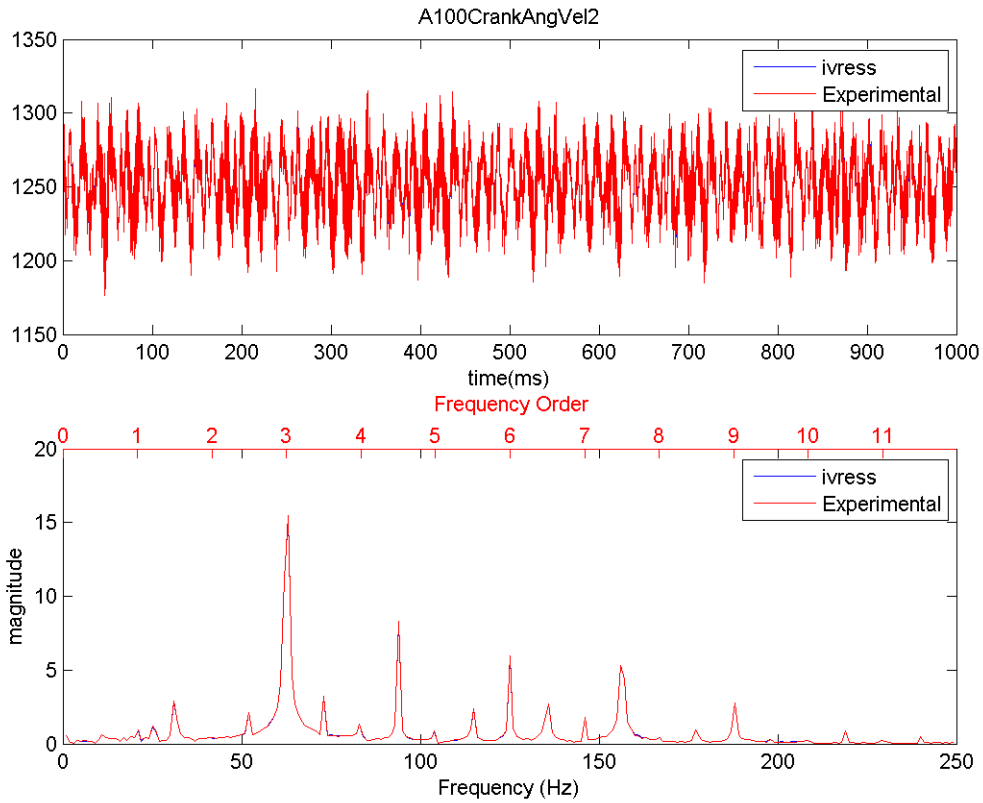

Figure 18 Crankshaft angular velocity in the A100 operation range with tensioner arm friction moment increases to 8 $N.m$ instead of 3.14 $N.m$

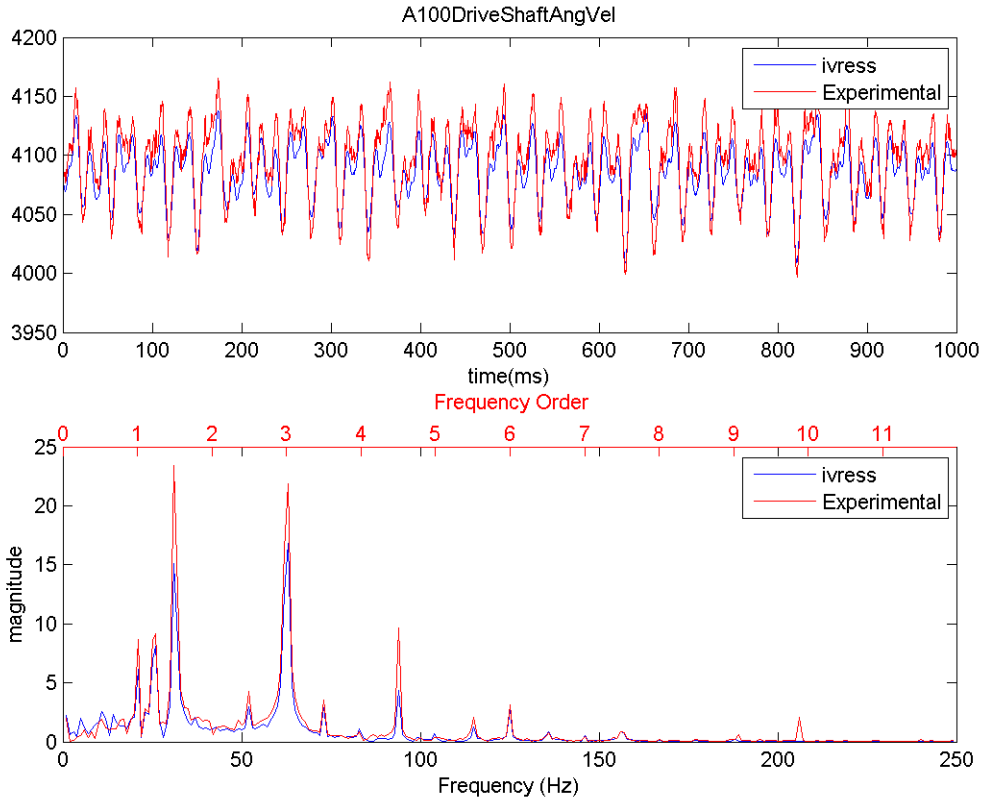

Figure 19 Drive shaft angular velocity in the A100 operation range with tensioner arm friction moment increases to 8 $N.m$ instead of 3.14 $N.m$

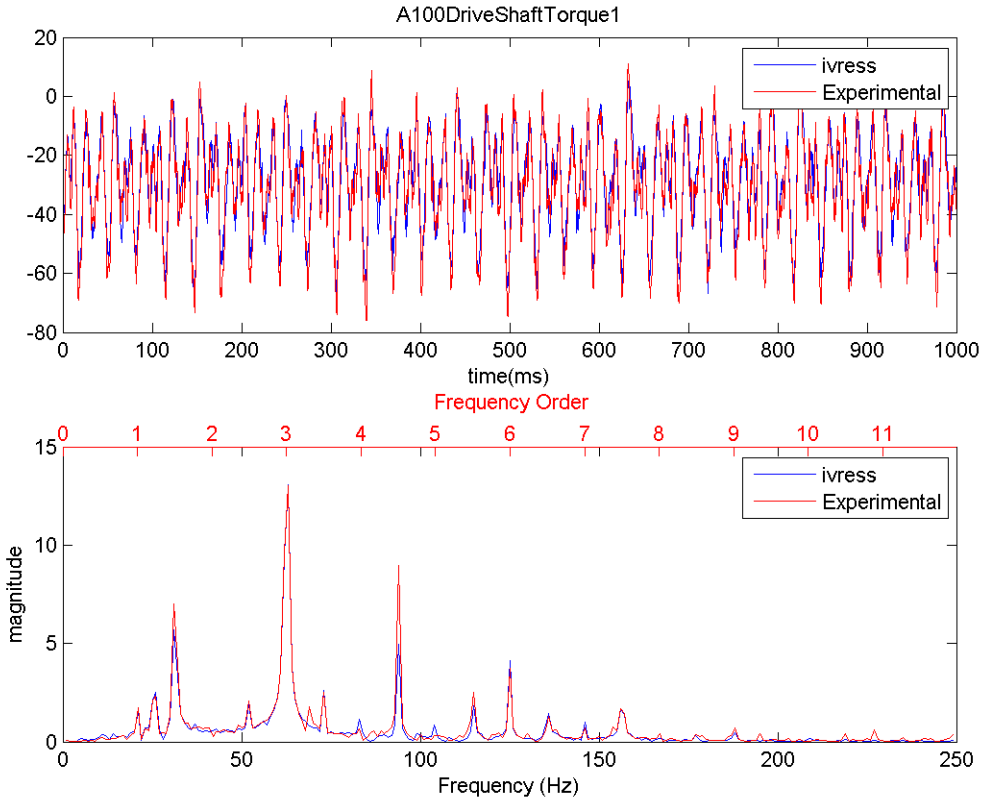

Figure 20 Drive shaft torque in the A100 operation range with tensioner arm friction moment increases to 8 $N.m$ instead of 3.14 $N.m$

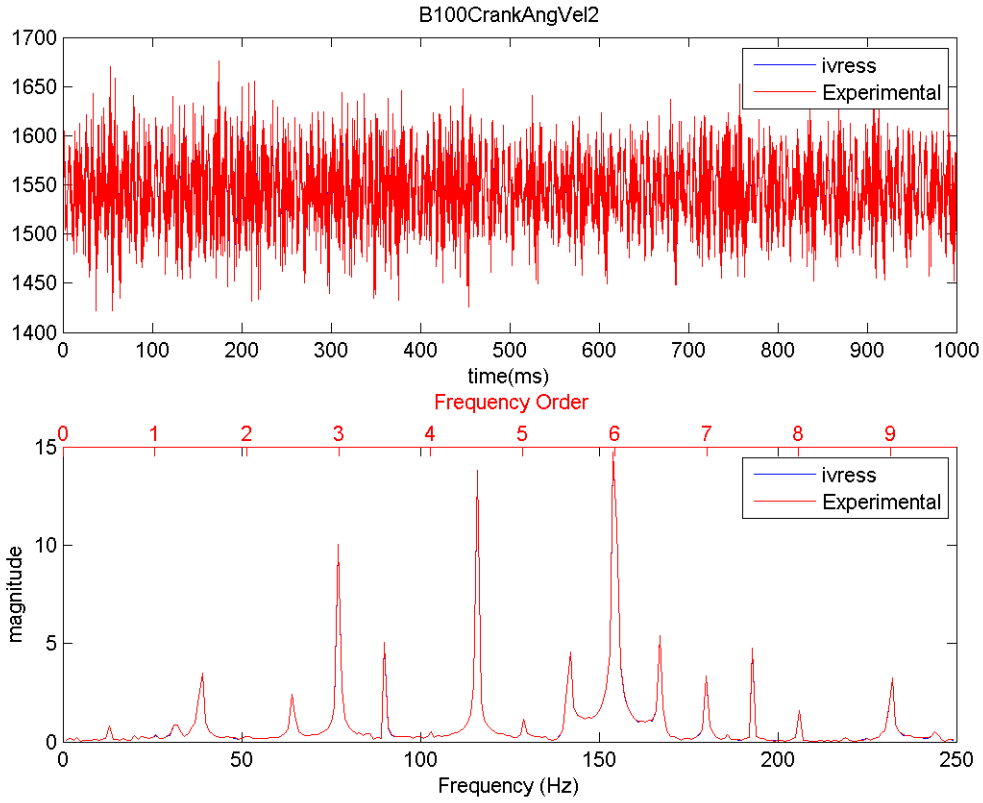

Figure 21 Crankshaft angular velocity in the B100 operation range with tensioner arm friction moment increases to 8 $N.m$ instead of 3.14 $N.m$

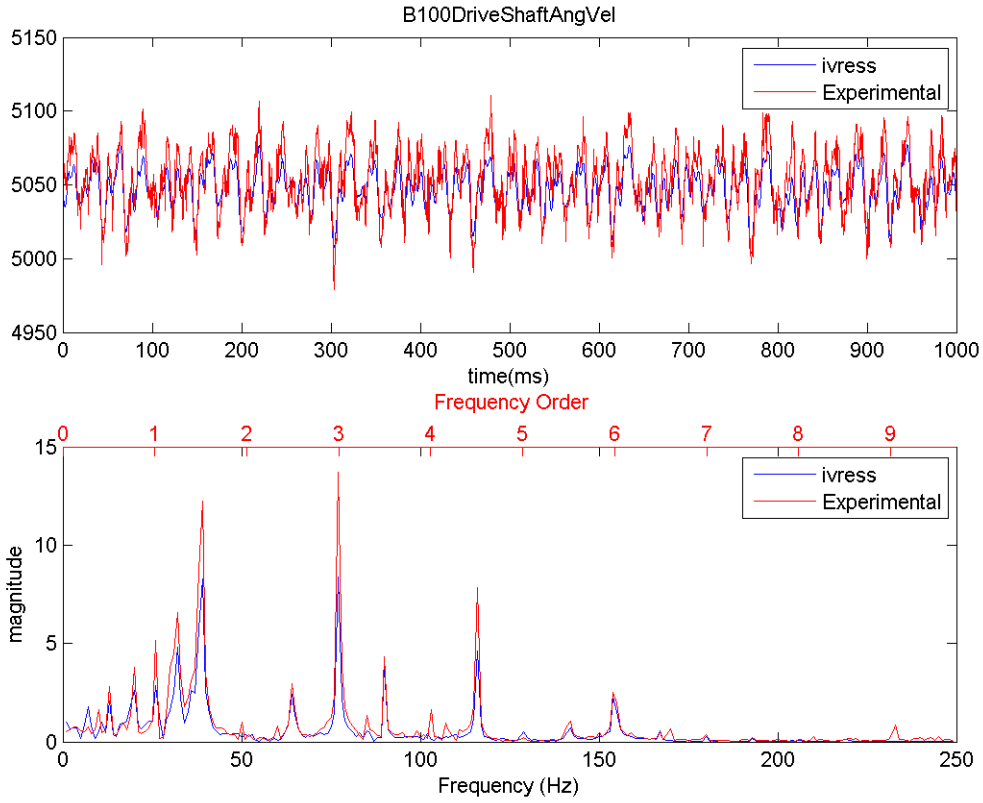

Figure 22 Drive shaft angular velocity in the B100 operation range with tensioner arm friction moment increases to 8 $N.m$ instead of 3.14 $N.m$

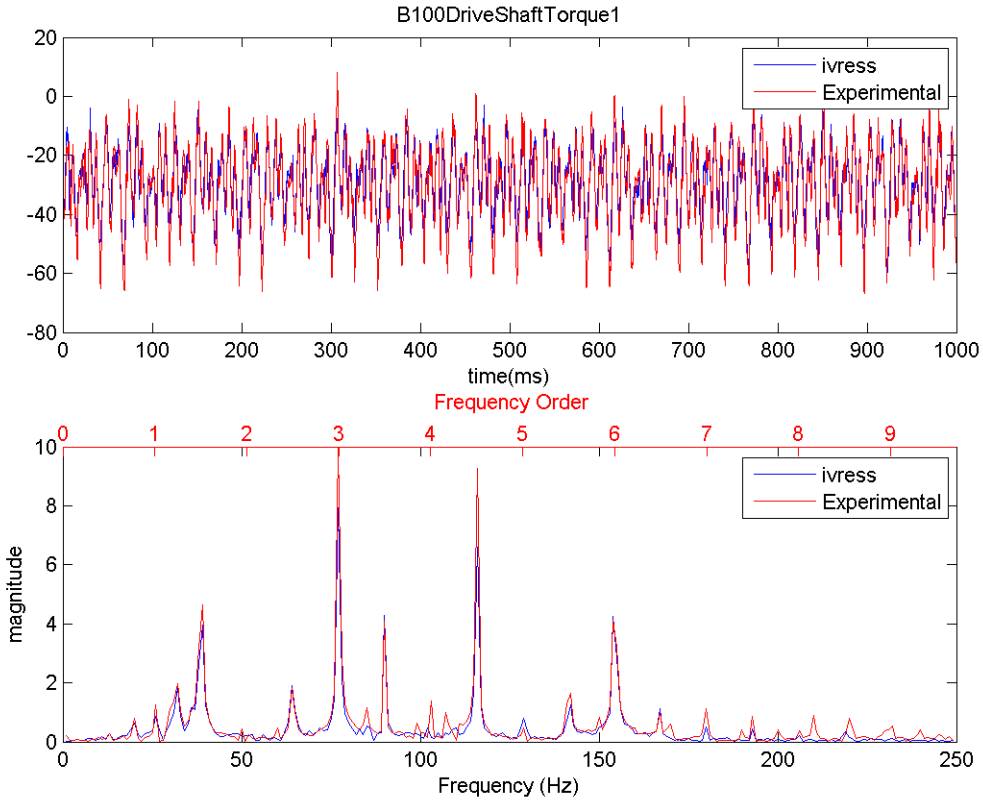

Figure 23 Drive shaft torque in the B100 operation range with tensioner arm friction moment increases to 8 $N.m$ instead of 3.14 $N.m$

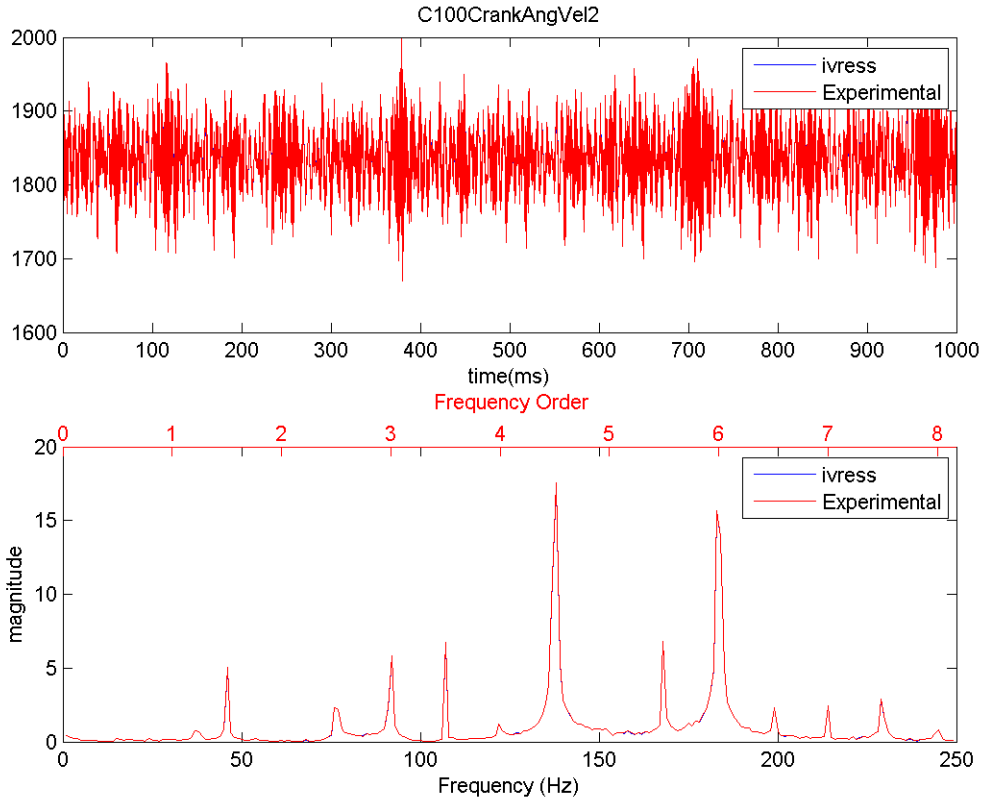

Figure 24 Crankshaft angular velocity in the C100 operation range with tensioner arm friction moment increases to 8 $N.m$ instead of 3.14 $N.m$

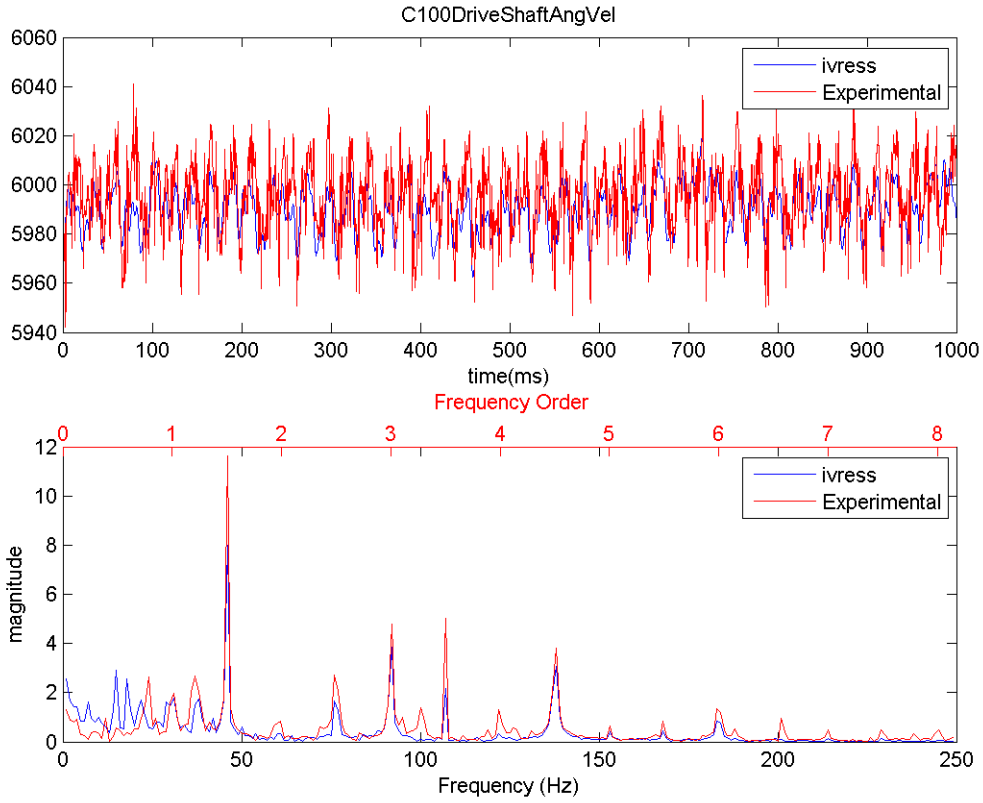

Figure 25 Drive shaft angular velocity in the C100 operation range with tensioner arm friction moment increases to 8 $N.m$ instead of 3.14 $N.m$

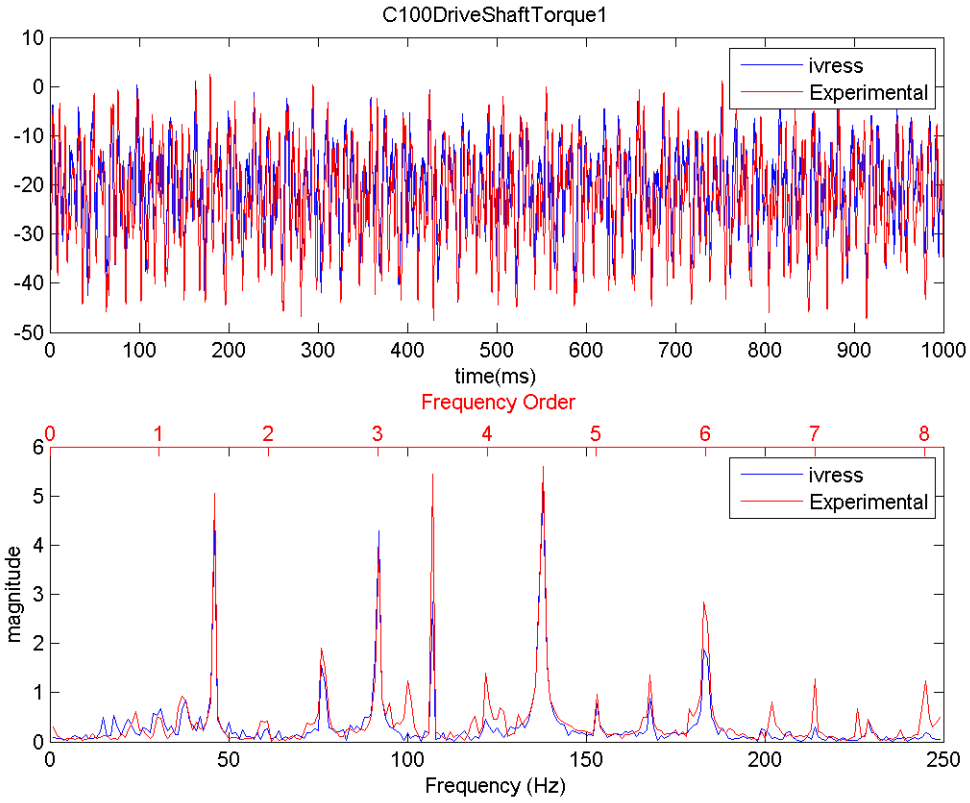

Figure 26 Drive shaft torque in the C100 operation range with tensioner arm friction moment increases to 8 $N.m$ instead of 3.14 $N.m$

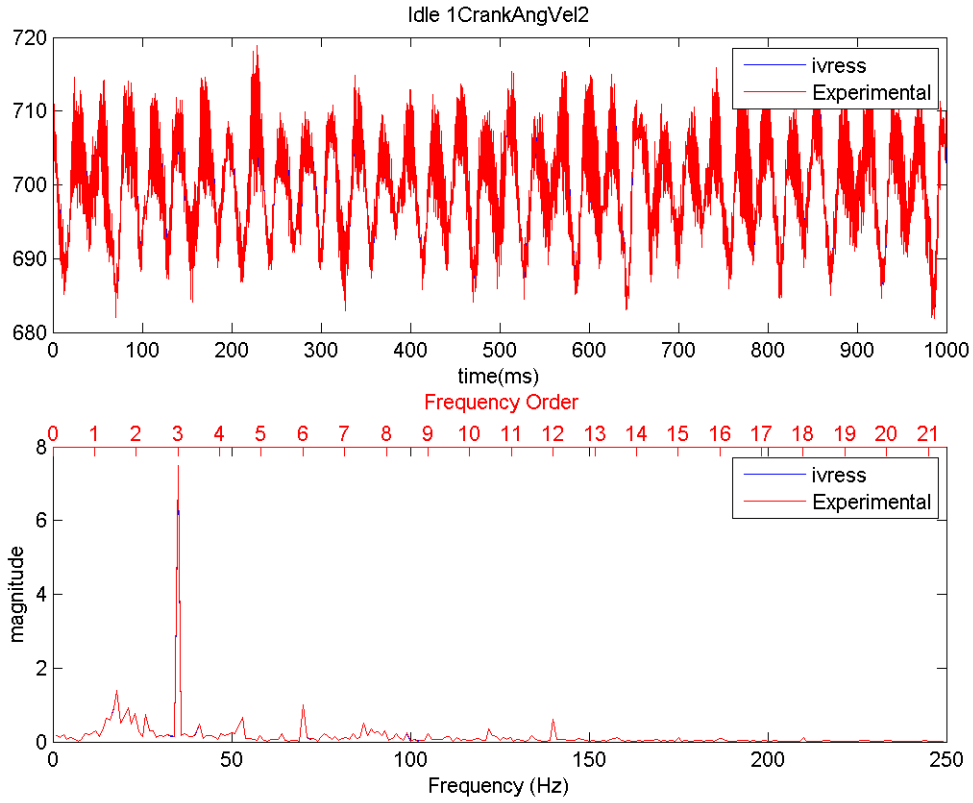

Figure 27 Crankshaft angular velocity in the idle operation range with tensioner arm friction moment increases to 8 $N.m$ instead of 3.14 $N.m$

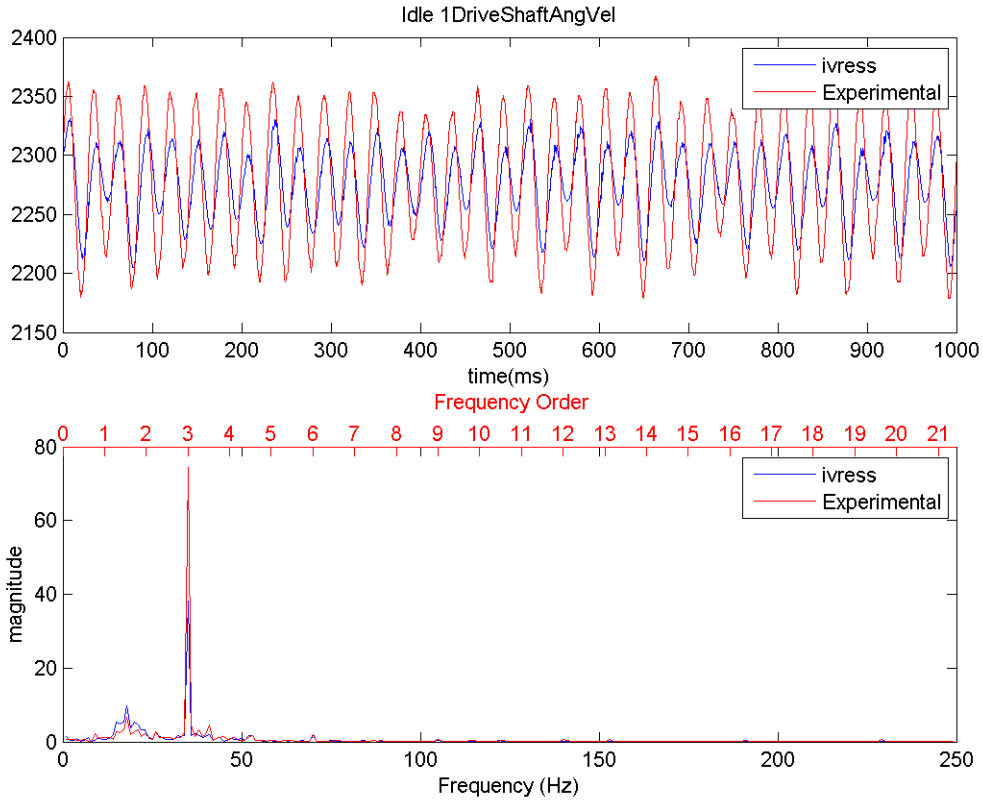

Figure 28 Drive shaft angular velocity in the idle operation range with tensioner arm friction moment increases to 8 $N.m$ instead of 3.14 $N.m$

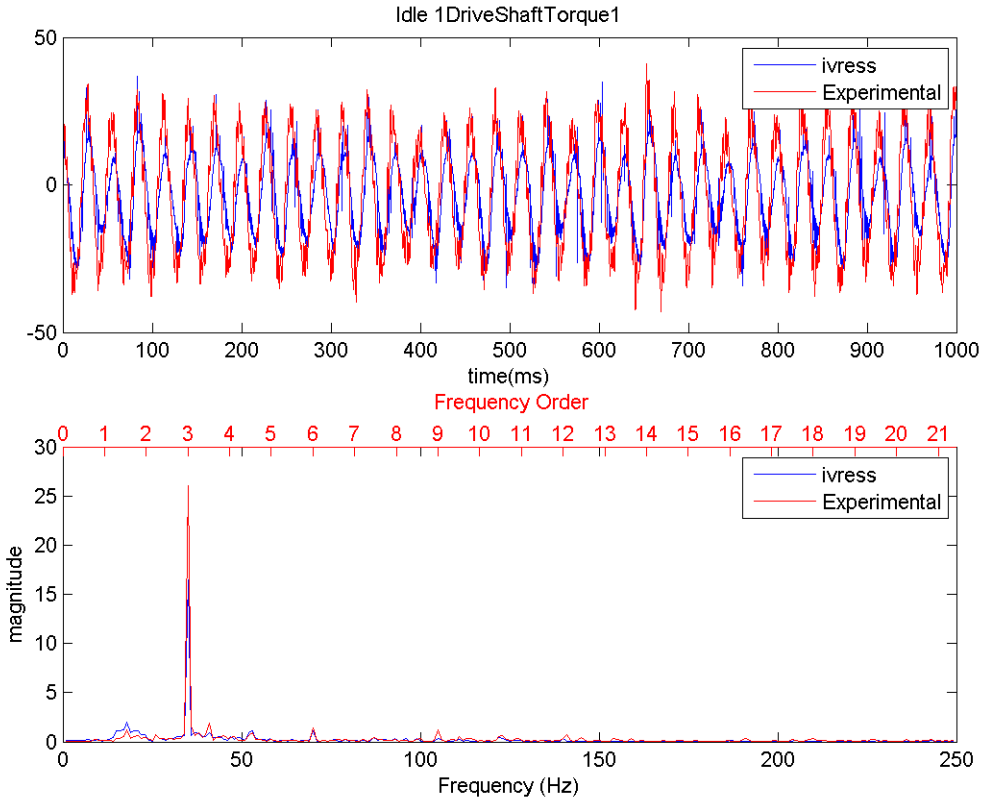

Figure 29 Drive shaft torque in the idle operation range with tensioner arm friction moment increases to 8 $N.m$ instead of 3.14 $N.m$

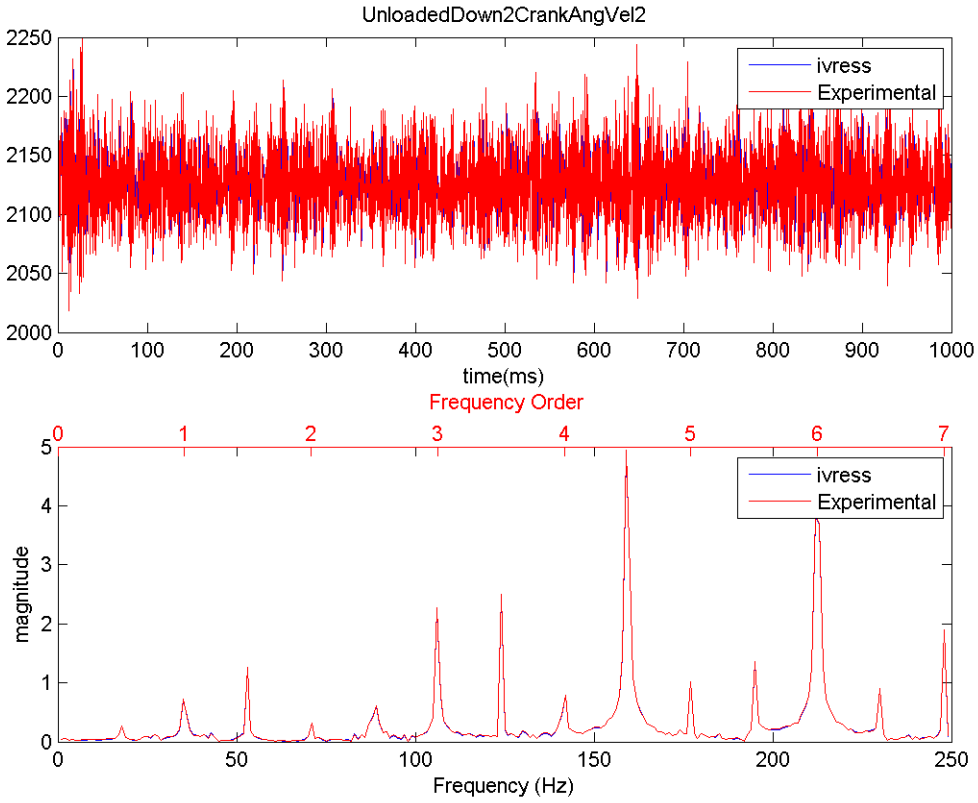

Figure 30 Crankshaft angular velocity in the UnloadedDown operation range with tensioner arm friction moment increases to 8 $N.m$ instead of 3.14 $N.m$

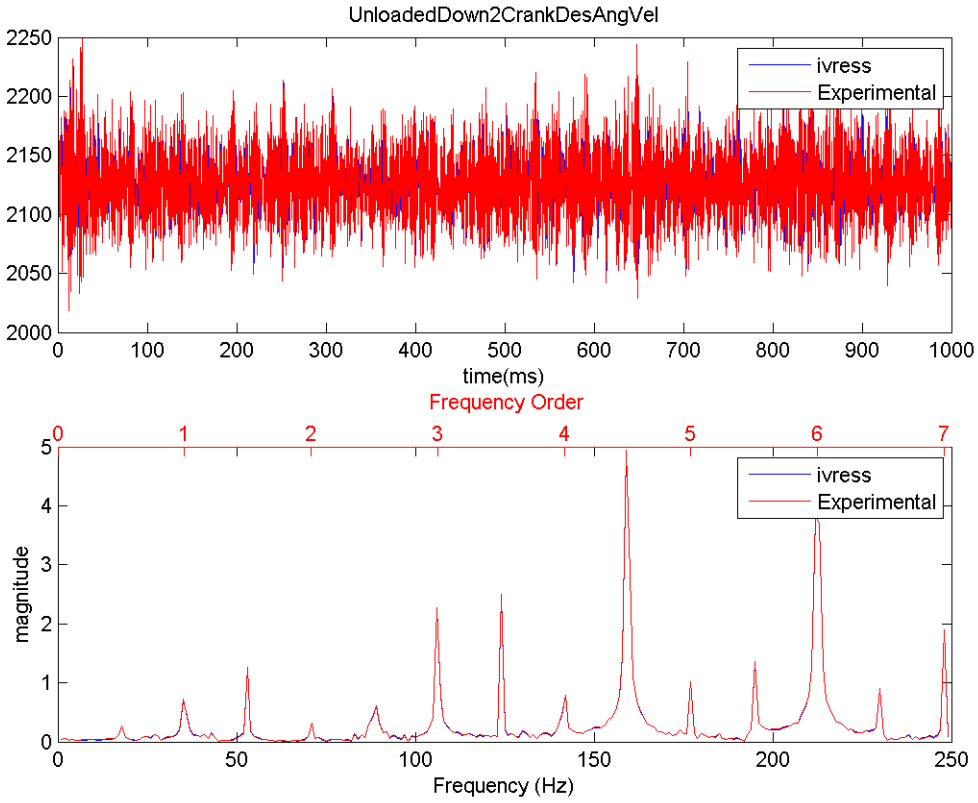

Figure 31 Drive shaft angular velocity in the UnloadedDown operation range with tensioner arm friction moment increases to 8 $N.m$ instead of 3.14 $N.m$

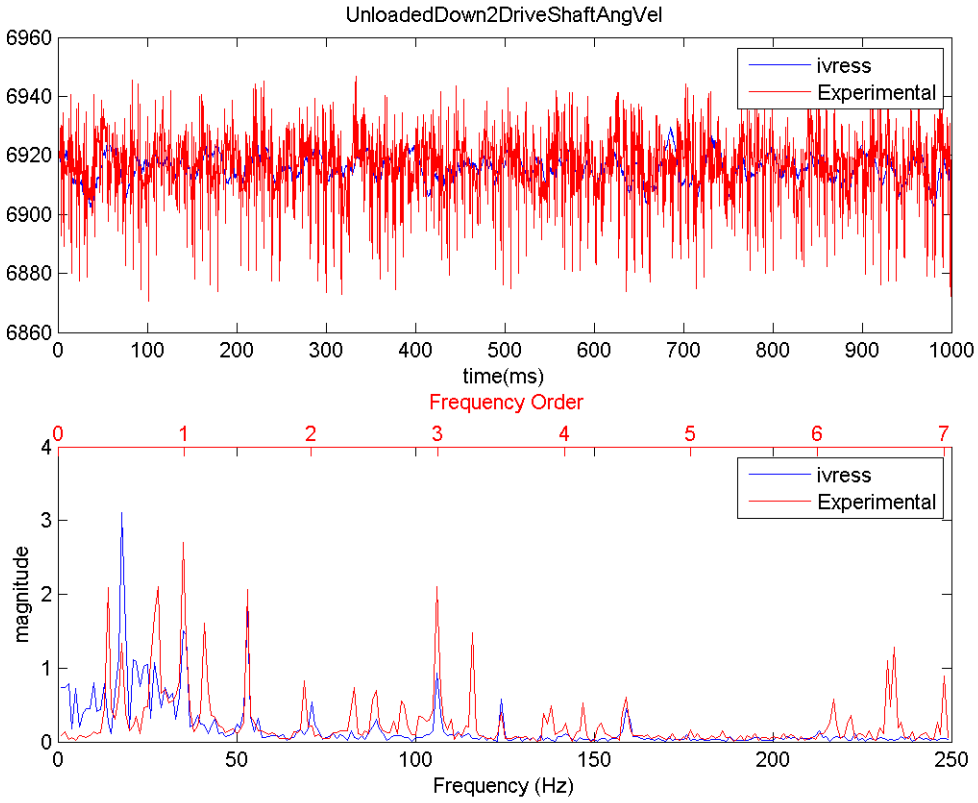

Figure 32 Drive shaft angular velocity in the UnloadedDown operation range with tensioner arm friction moment increases to 8 $N.m$ instead of 3.14 $N.m$

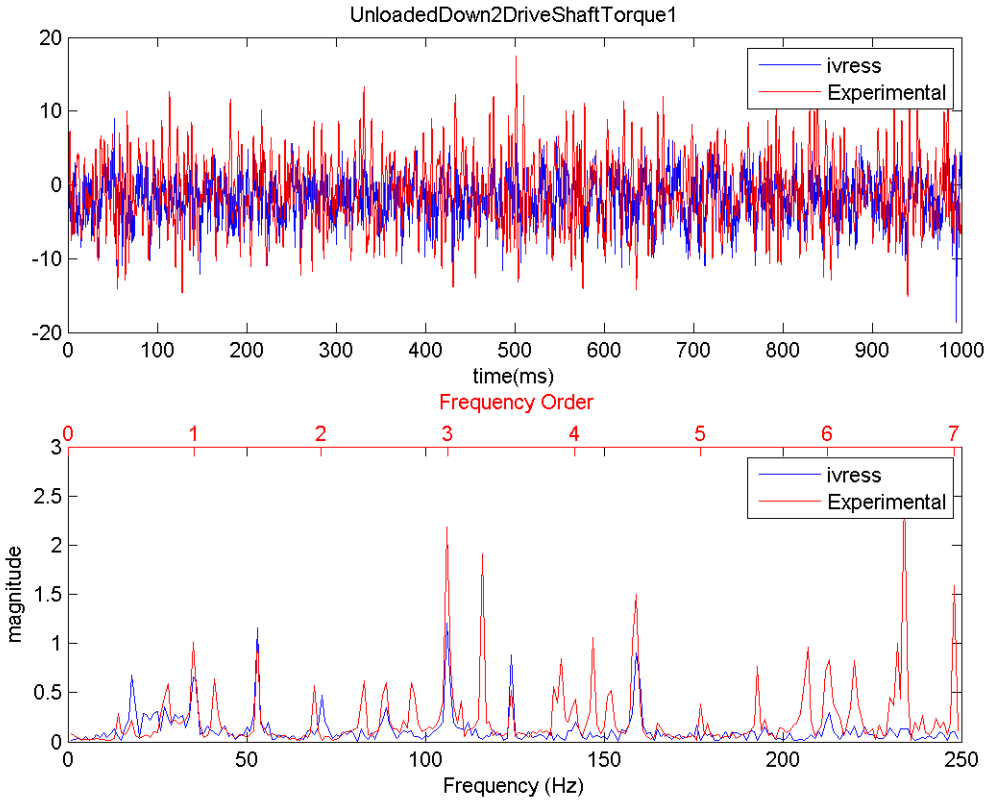

Figure 33 Drive shaft torque in the UnloadedDown operation range with tensioner arm friction moment increases to 8 $N.m$ instead of 3.14 $N.m$

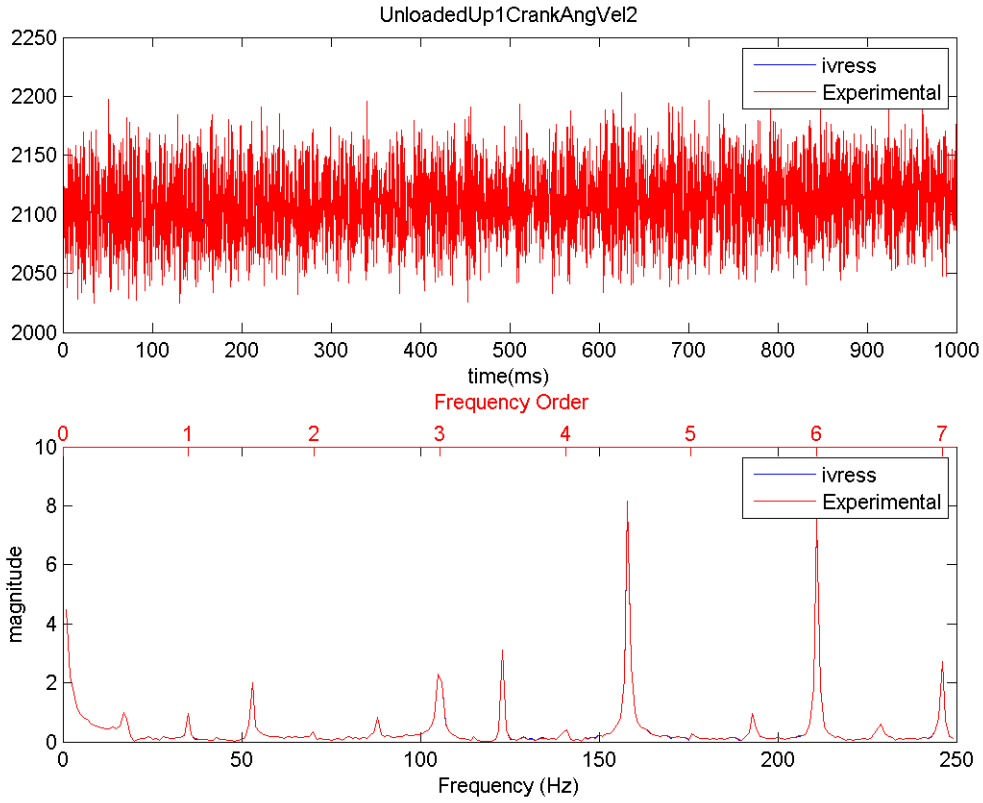

Figure 34 Crankshaft angular velocity in the UnloadedUp operation range with tensioner arm friction moment increases to 8 $N.m$ instead of 3.14 $N.m$

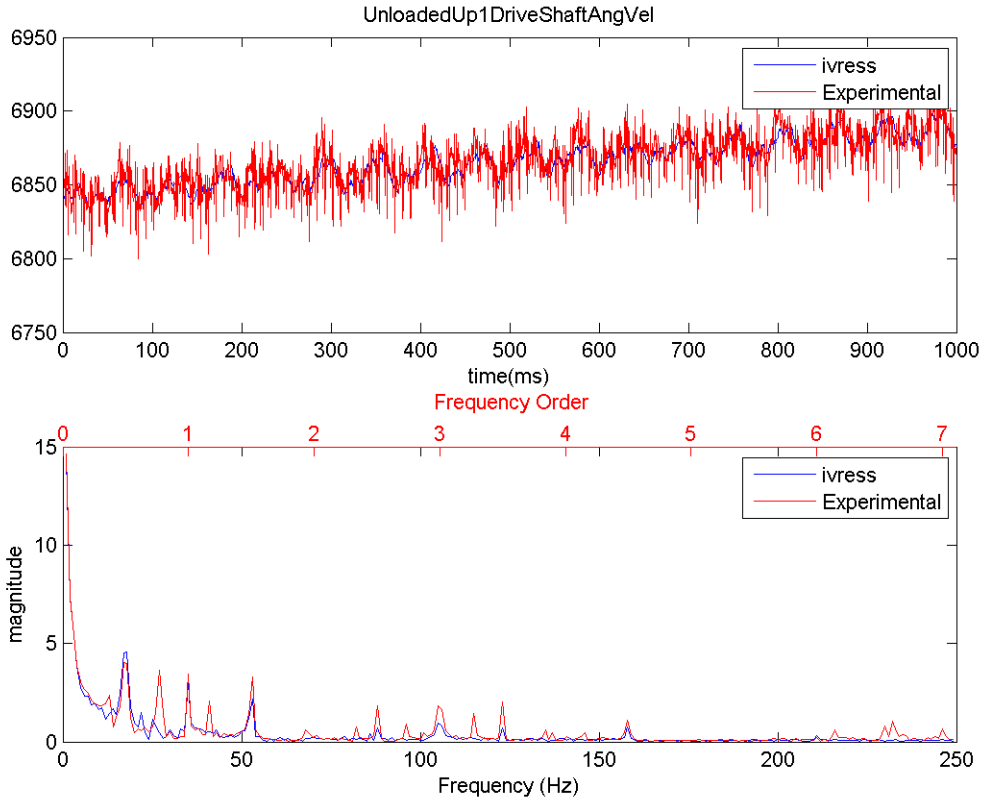

Figure 35 Drive shaft angular velocity in the UnloadedUp operation range with tensioner arm friction moment increases to 8 $N.m$ instead of 3.14 $N.m$

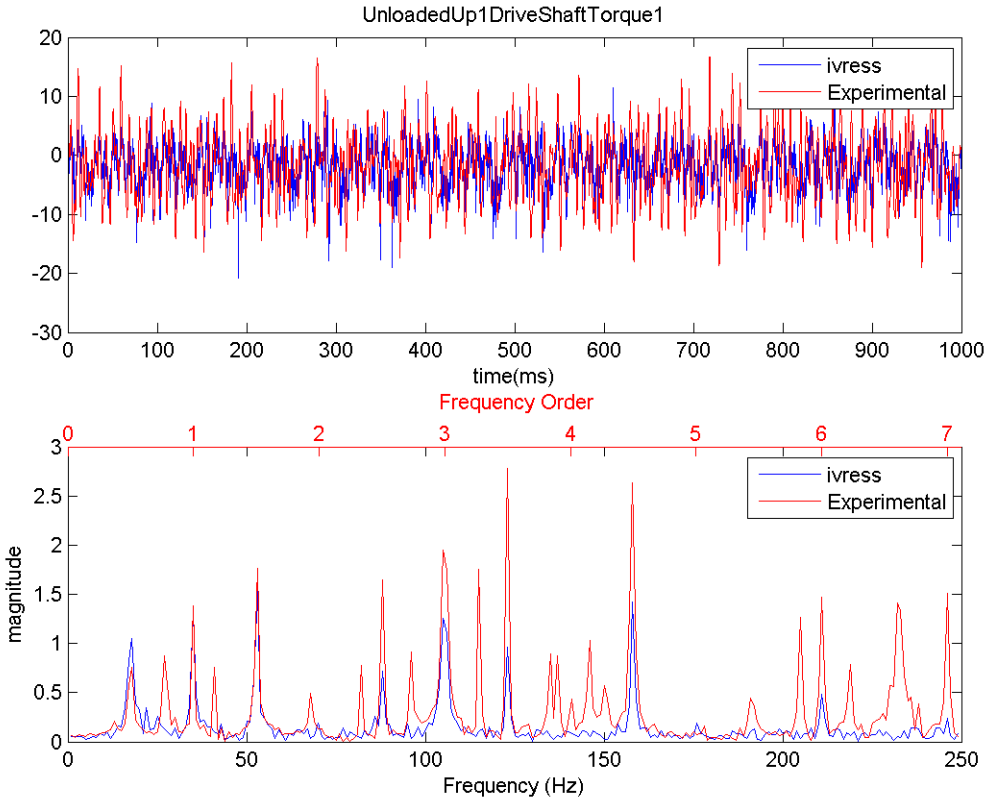

Figure 36 Drive shaft torque in the UnloadedUp operation range with tensioner arm friction moment increases to 8 $N.m$ instead of 3.14 $N.m$

3 Belt Axial Damping (CA) Increases to 15 $N.s$ instead of 10 $N.s$

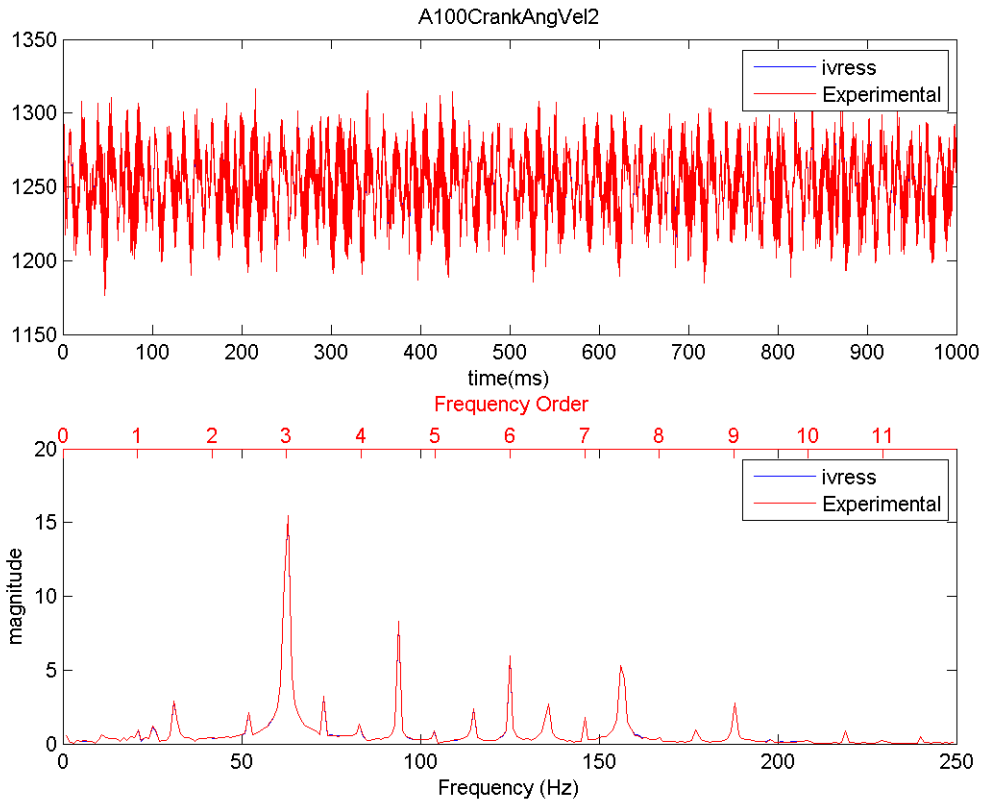

Figure 37 Crankshaft angular velocity in the A100 operation range with belt axial damping (CA) increases to 15 $N.s$ instead of 10 $N.s$

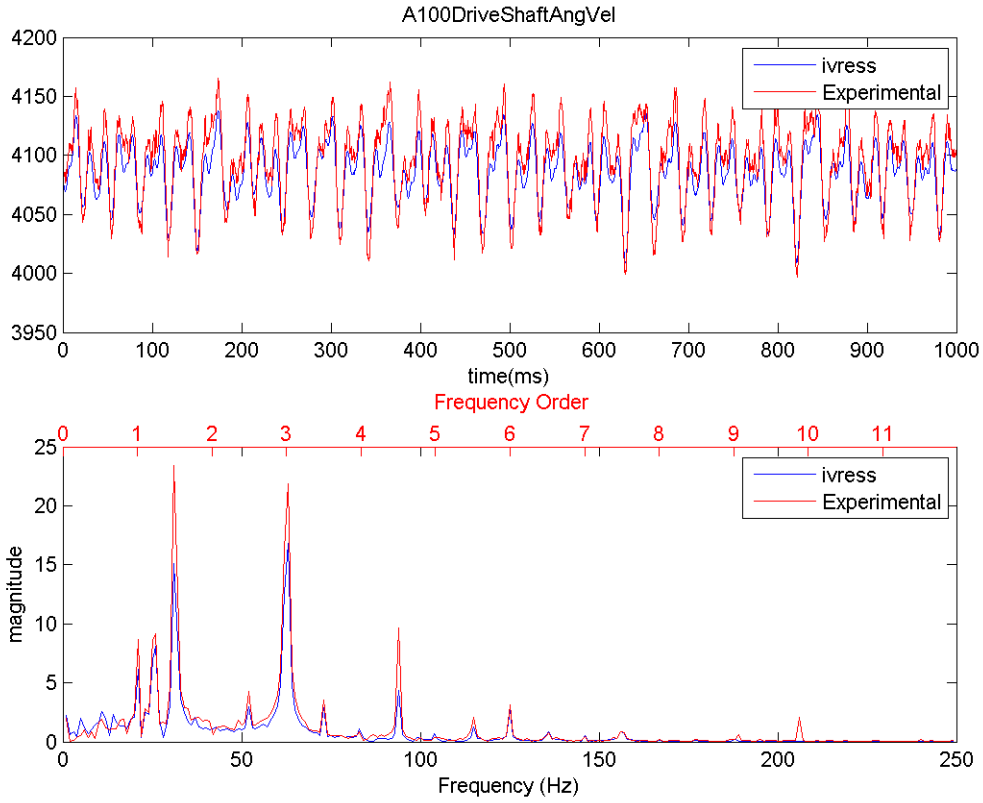

Figure 38 Drive shaft angular velocity in the A100 operation range with belt axial damping (CA) increases to 15 $N.s$ instead of 10 $N.s$

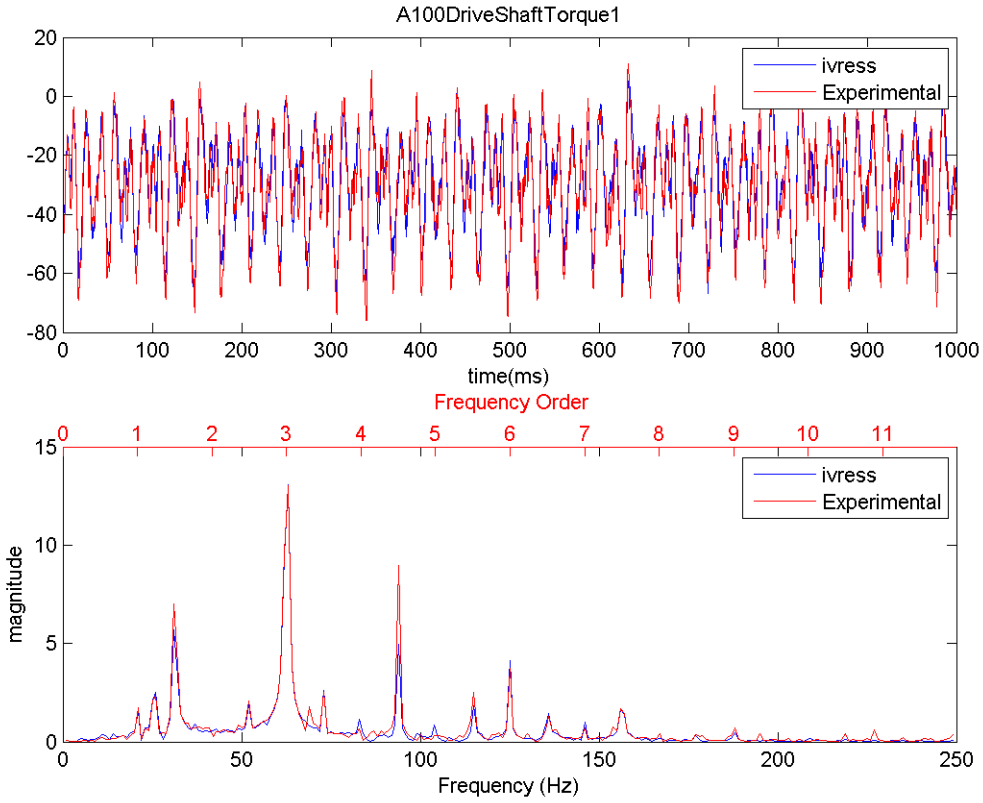

Figure 39 Drive shaft torque in the A100 operation range with belt axial damping (CA) increases to 15 $N.s$ instead of 10 $N.s$

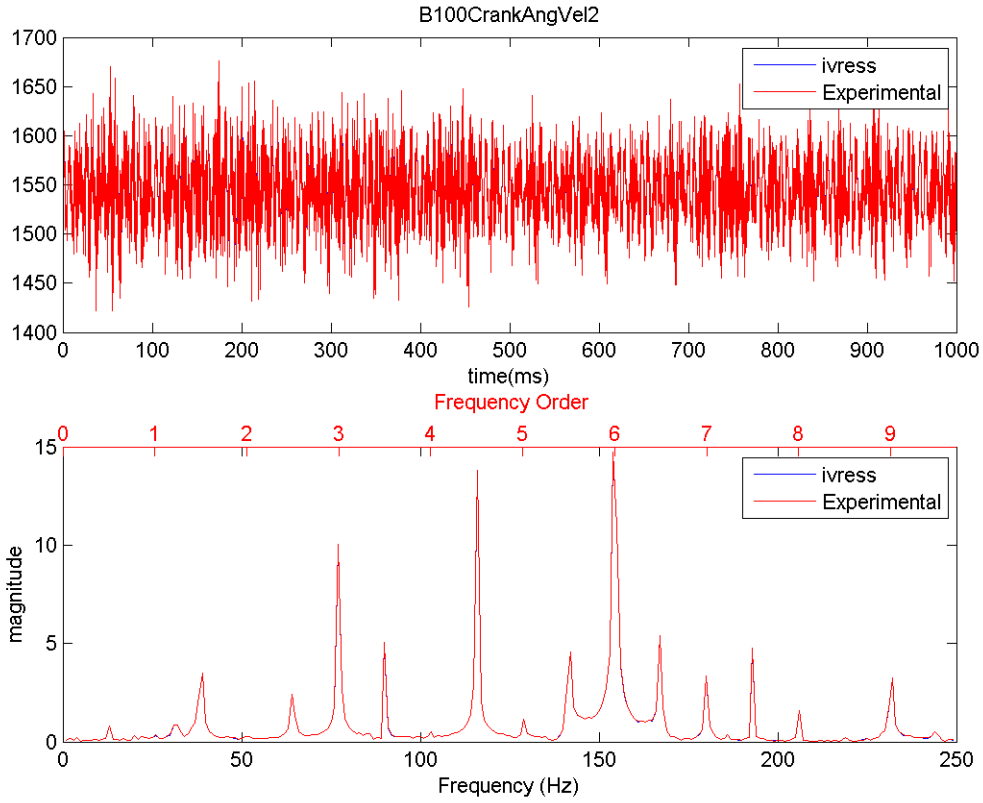

Figure 40 Crankshaft angular velocity in the B100 operation range with belt axial damping (CA) increases to 15 $N.s$ instead of 10 $N.s$

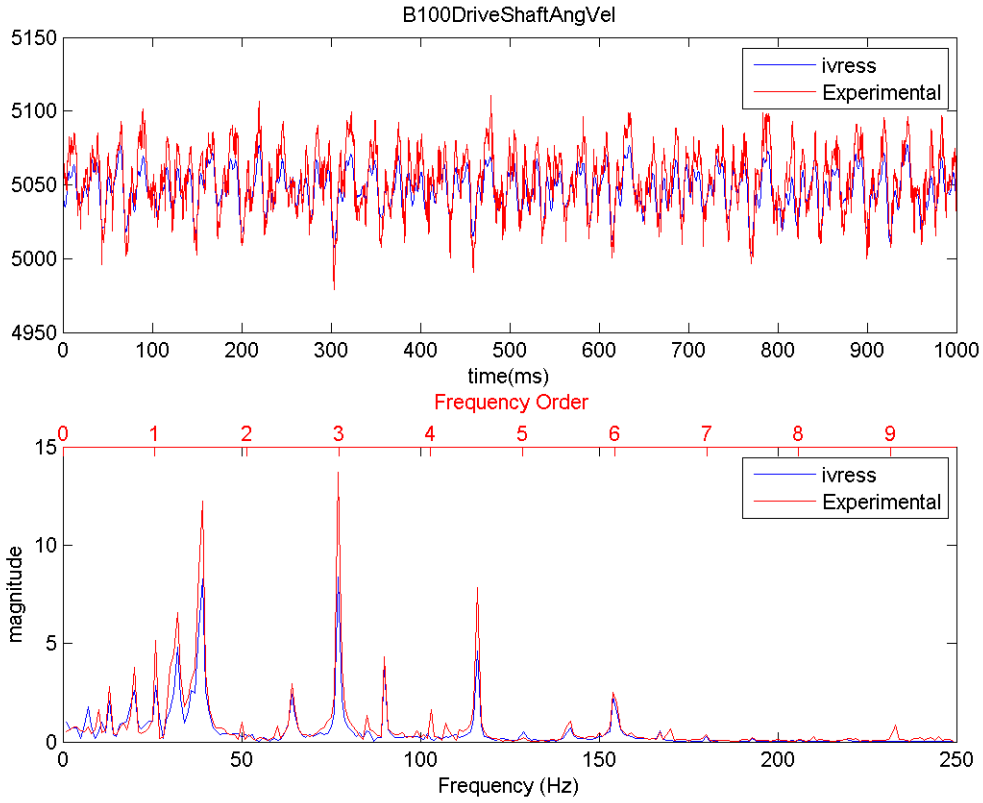

Figure 41 Drive shaft angular velocity in the B100 operation range with belt axial damping (CA) increases to 15 $N.s$ instead of 10 $N.s$

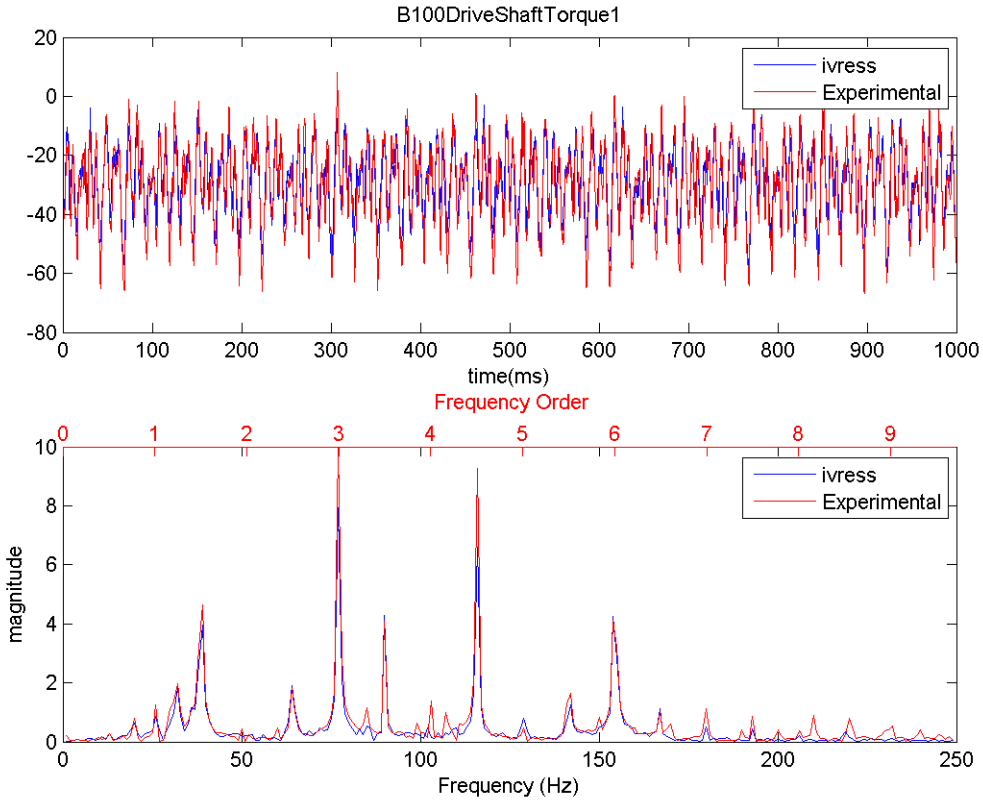

Figure 42 Drive shaft torque in the B100 operation range with belt axial damping (CA) increases to 15 $N.s$ instead of 10 $N.s$

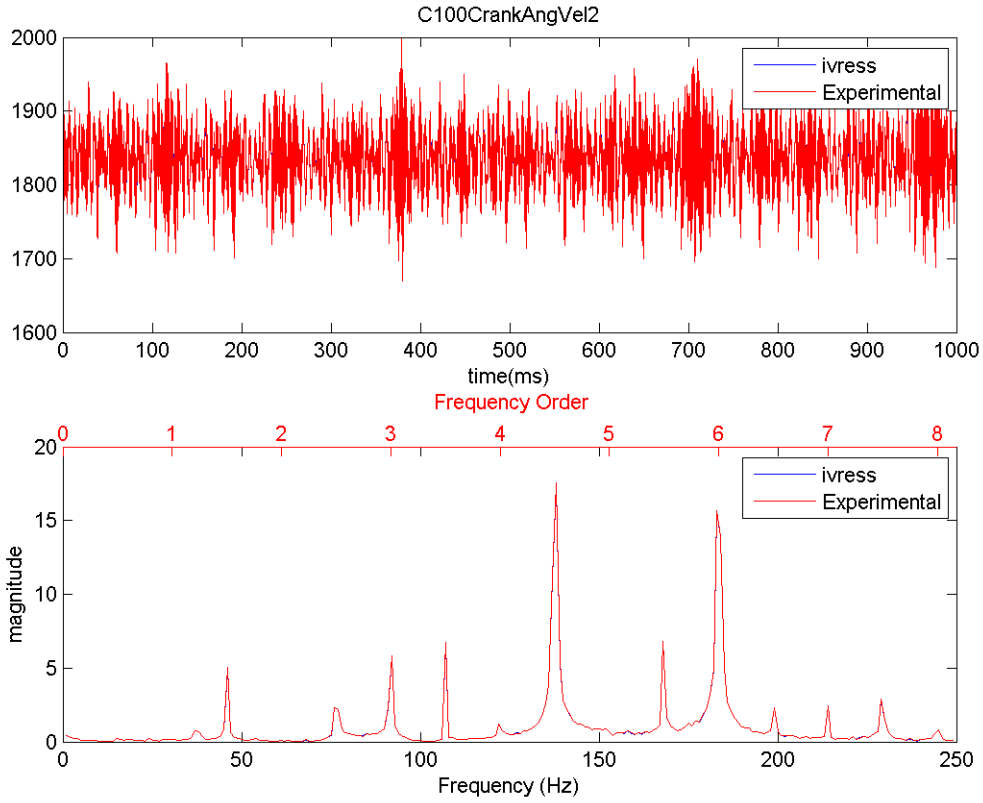

Figure 43 Crankshaft angular velocity in the C100 operation range with belt axial damping (CA) increases to 15 $N.s$ instead of 10 $N.s$

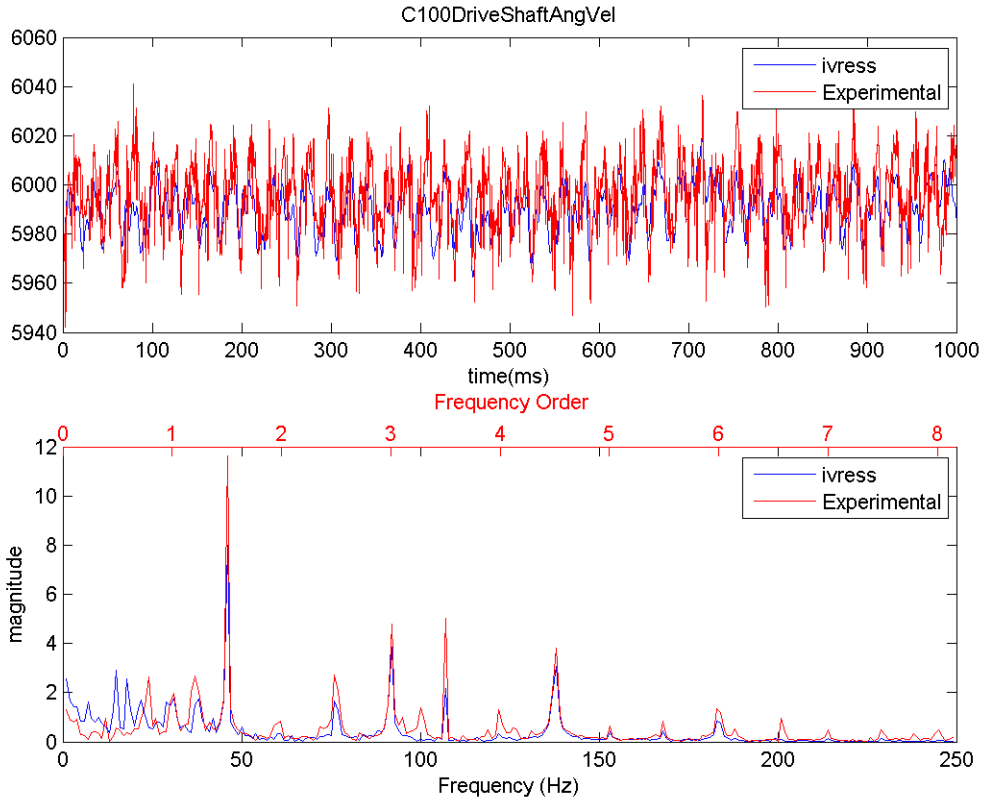

Figure 44 Drive shaft angular velocity in the C100 operation range with belt axial damping (CA) increases to 15 $N.s$ instead of 10 $N.s$

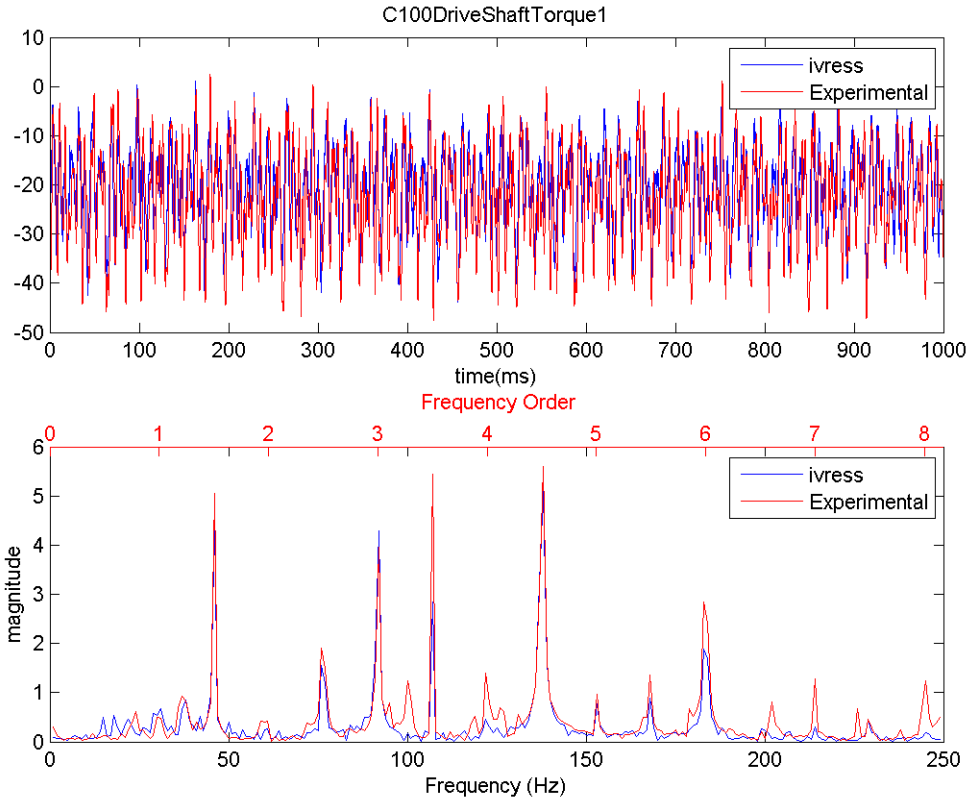

Figure 45 Drive shaft torque in the C100 operation range with belt axial damping (CA) increases to 15 $N.s$ instead of 10 $N.s$

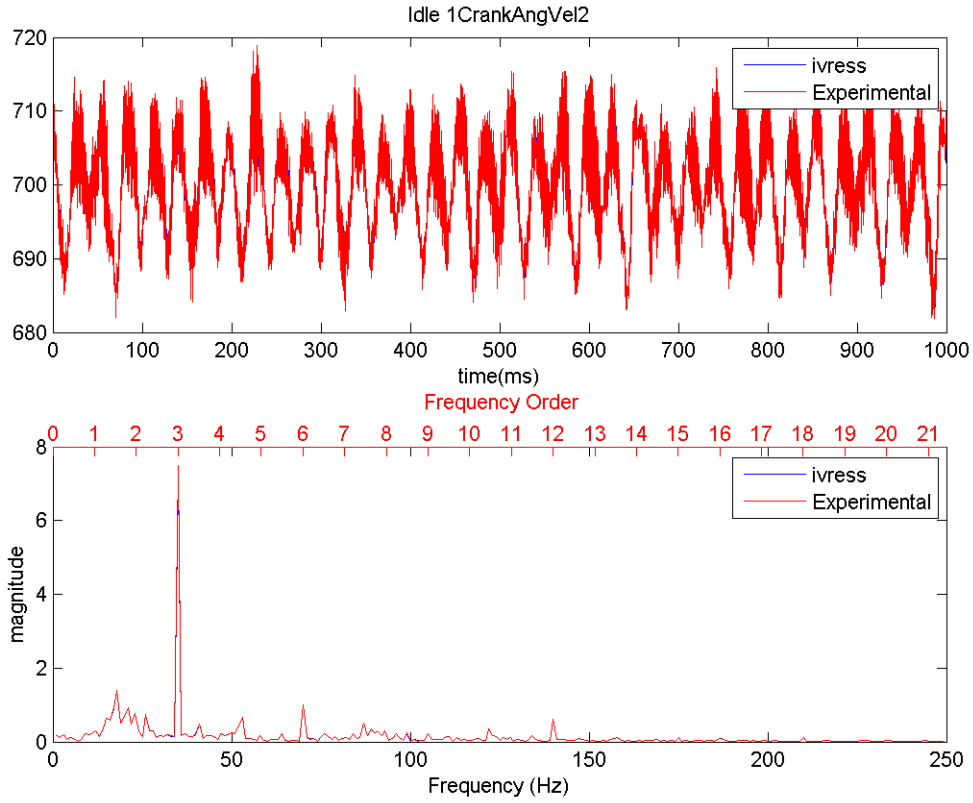

Figure 46 Crankshaft angular velocity in the idle operation range with belt axial damping (CA) increases to 15 $N.s$ instead of 10 $N.s$

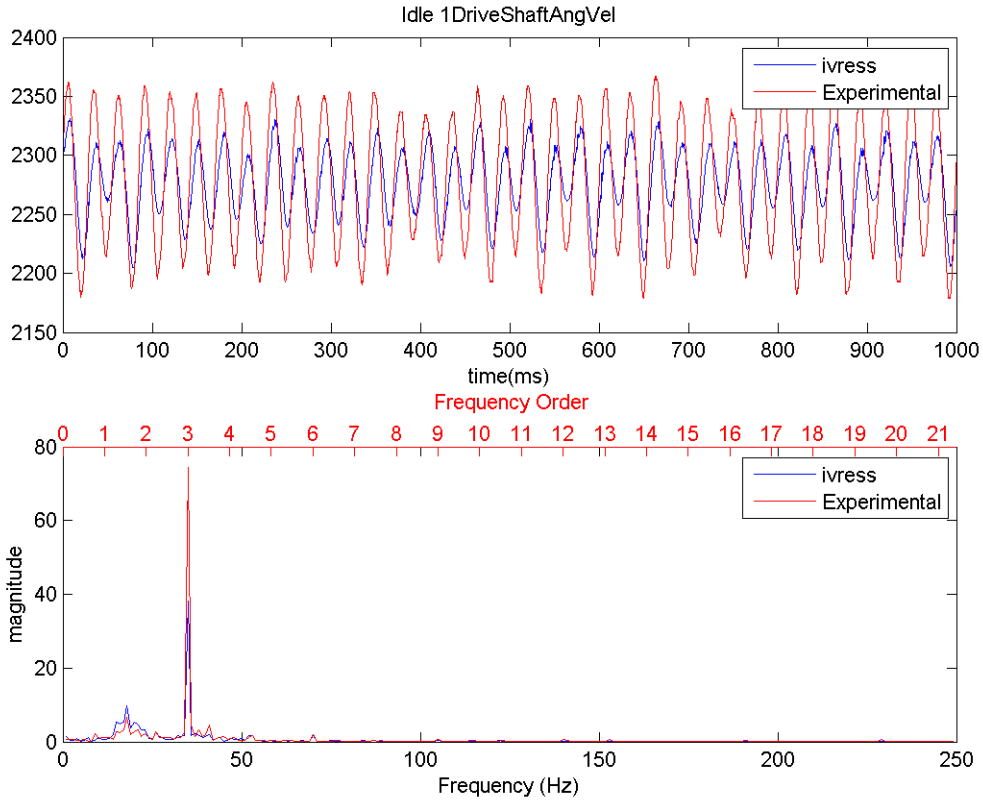

Figure 47 Drive shaft angular velocity in the idle operation range with belt axial damping (CA) increases to 15 $N.s$ instead of 10 $N.s$

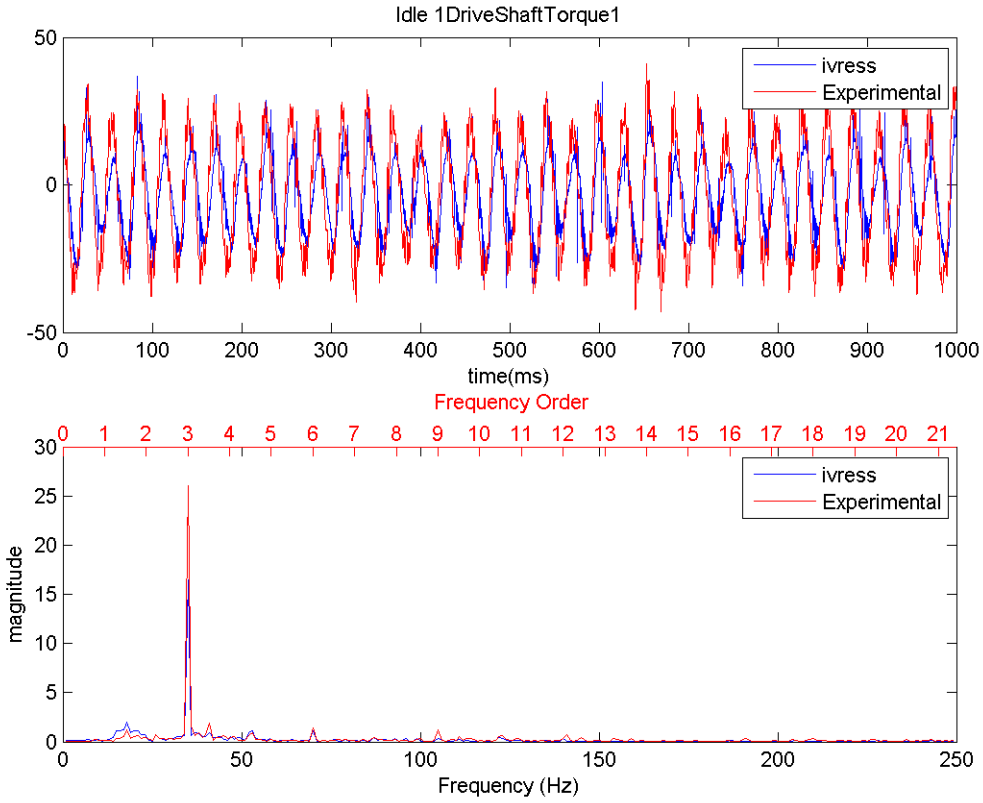

Figure 48 Drive shaft torque in the idle operation range with belt axial damping (CA) increases to 15 $N.s$ instead of 10 $N.s$

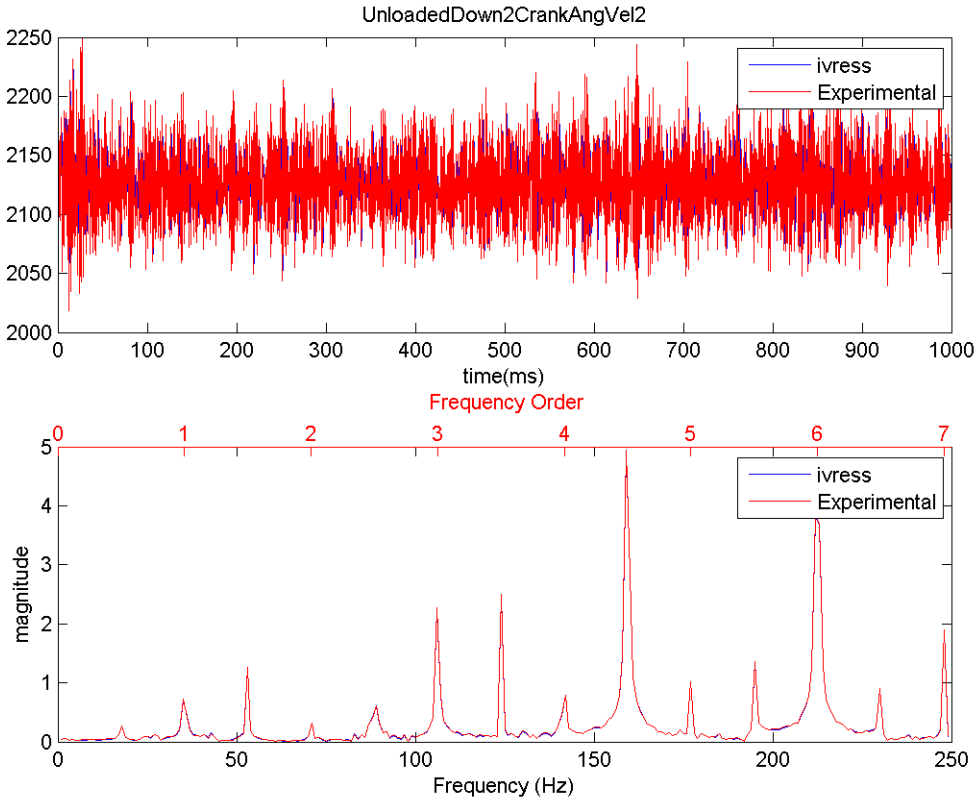

Figure 49 Crankshaft angular velocity in the UnloadedDown operation range with belt axial damping (CA) increases to 15 $N.s$ instead of 10 $N.s$

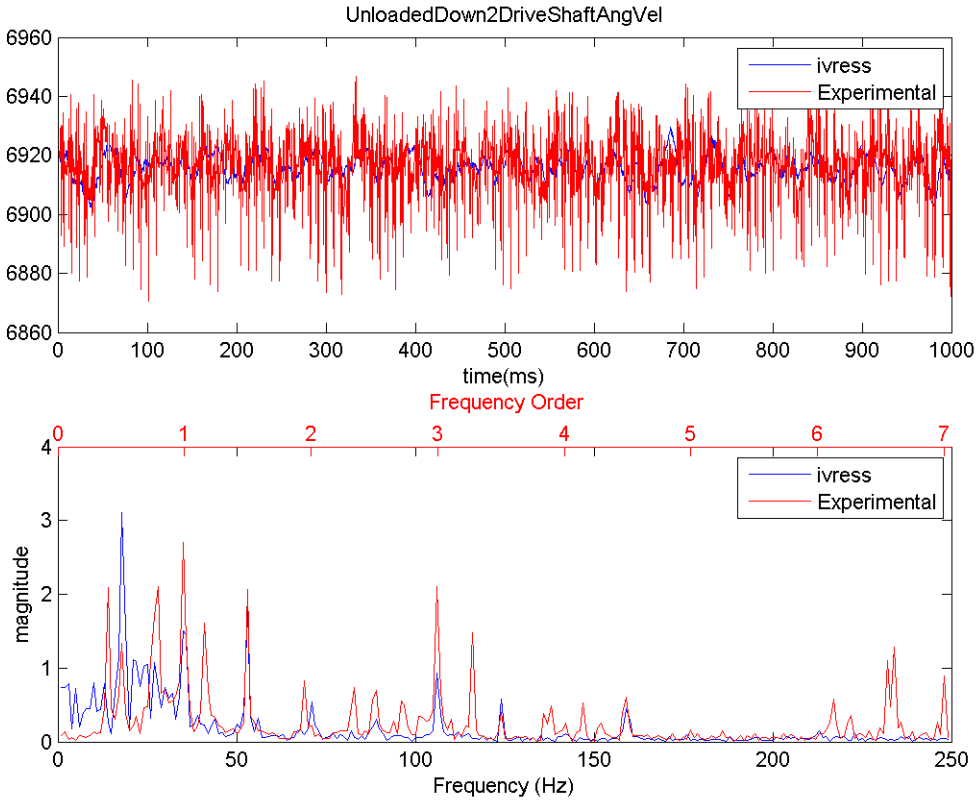

Figure 50 Drive shaft angular velocity in the UnloadedDown operation range with belt axial damping (CA) increases to 15 $N.s$ instead of 10 $N.s$

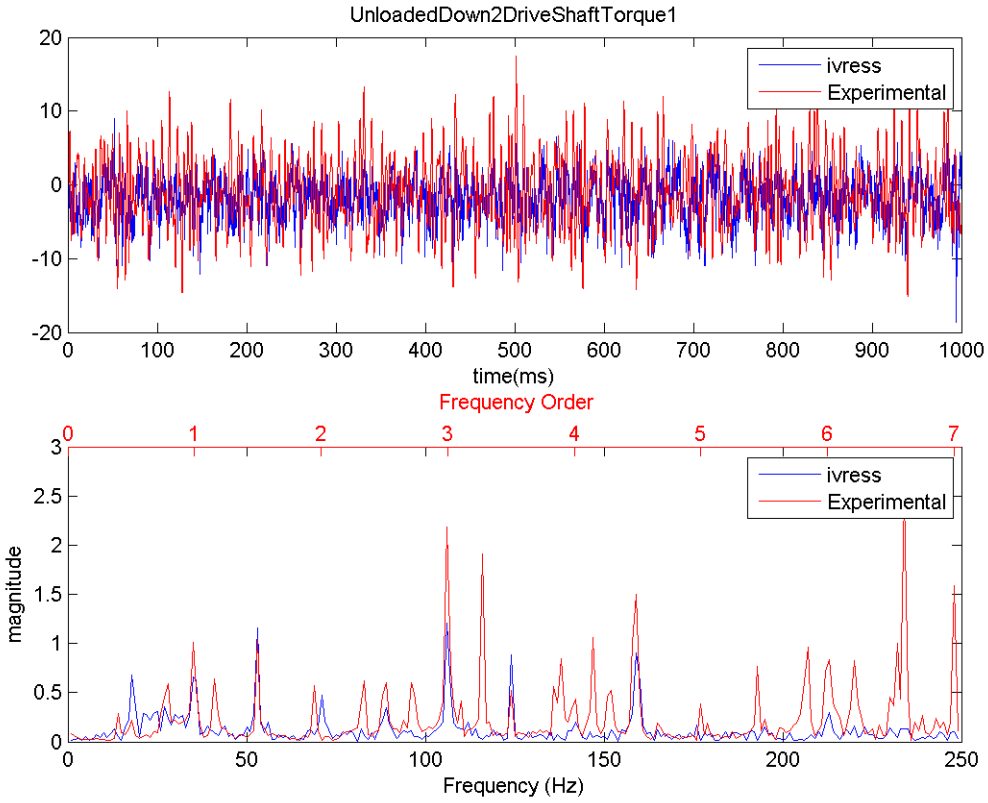

Figure 51 Drive shaft torque in the UnloadedDown operation range with belt axial damping (CA) increases to 15 $N.s$ instead of 10 $N.s$

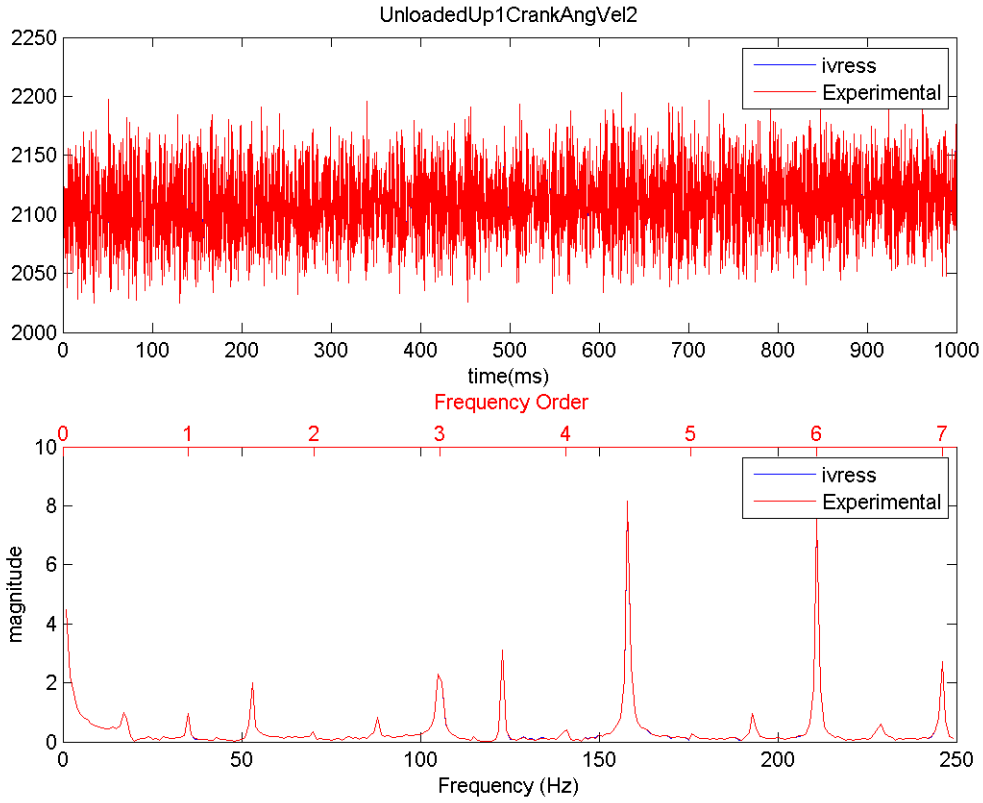

Figure 52 Crankshaft angular velocity in the UnloadedUp operation range with belt axial damping (CA) increases to 15 $N.s$ instead of 10 $N.s$

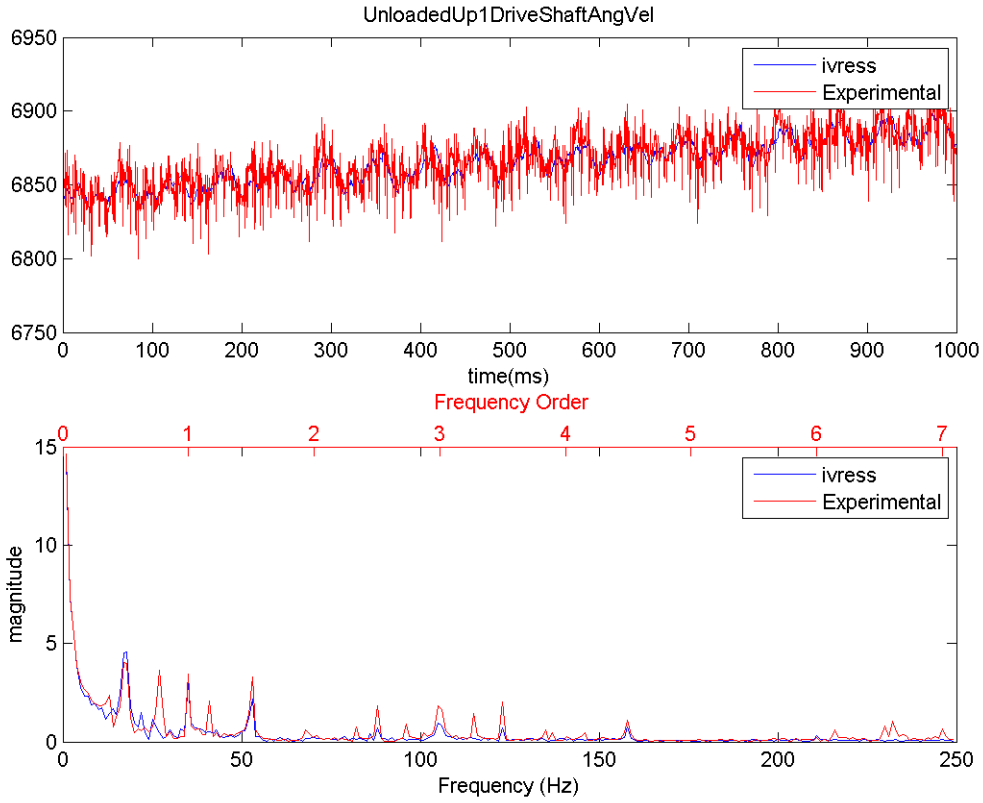

Figure 53 Drive shaft angular velocity in the UnloadedUp operation range with belt axial damping (CA) increases to 15 $N.s$ instead of 10 $N.s$

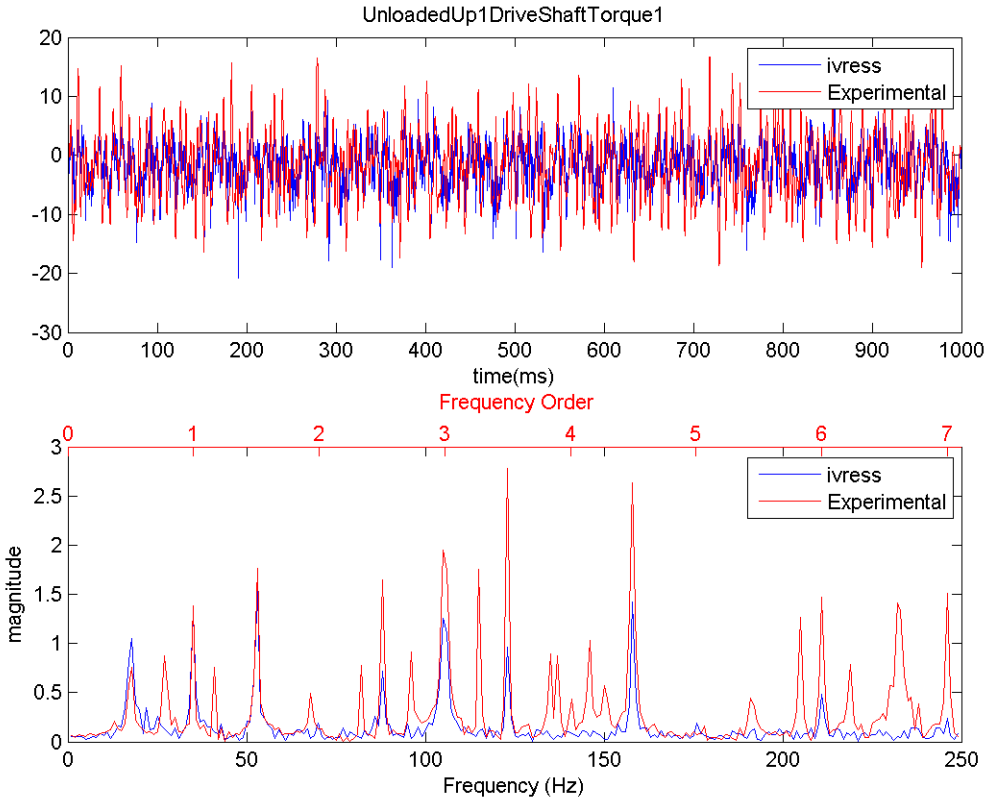

Figure 54 Drive shaft torque in the UnloadedUp operation range with belt axial damping (CA) increases to 15 $N.s$ instead of 10 $N.s$

4 Belt axial stiffness (EA) decreases to 110,000 N instead of 140,563 N in the base line

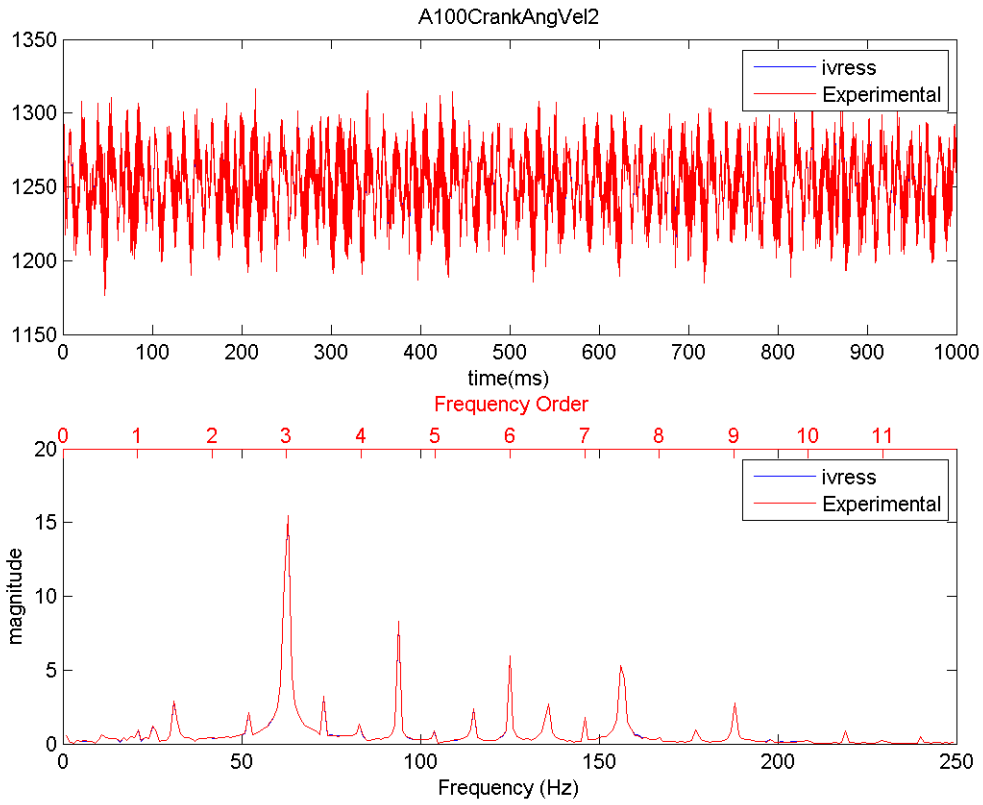

Figure 55 Crankshaft angular velocity in the A100 operation range with belt axial stiffness (EA) = 110,000 N instead of 140,563 N in the base line

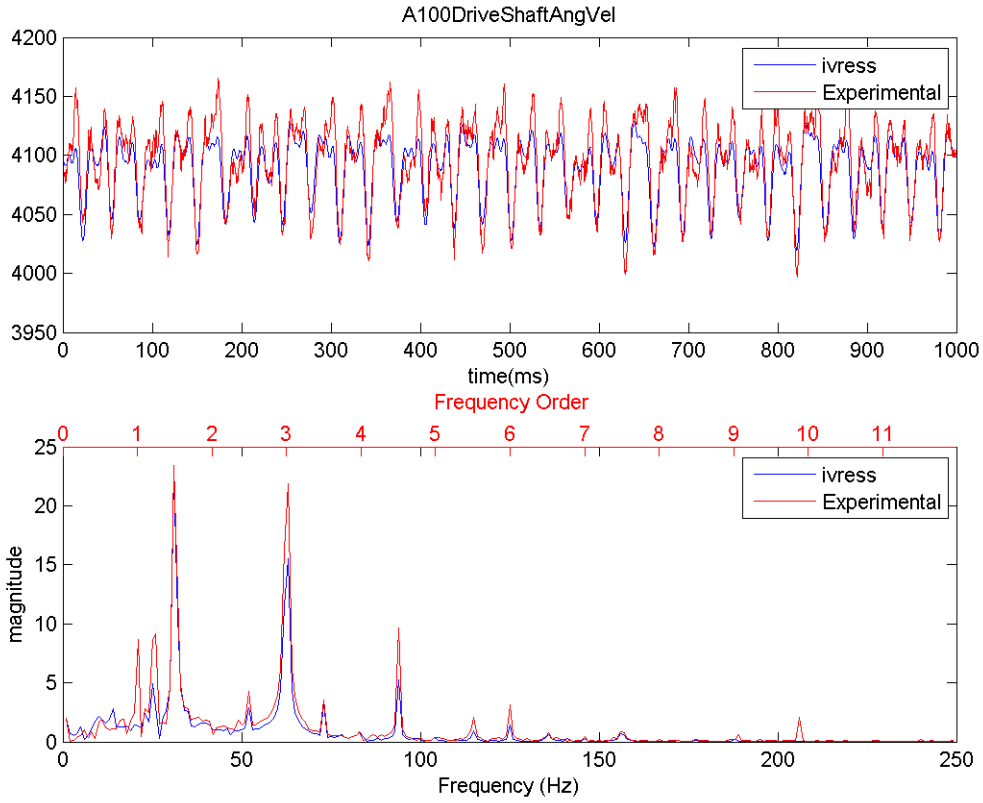

Figure 56 Drive shaft angular velocity in the A100 operation range with belt axial stiffness (EA) = 110,000 N instead of 140,563 N in the base line

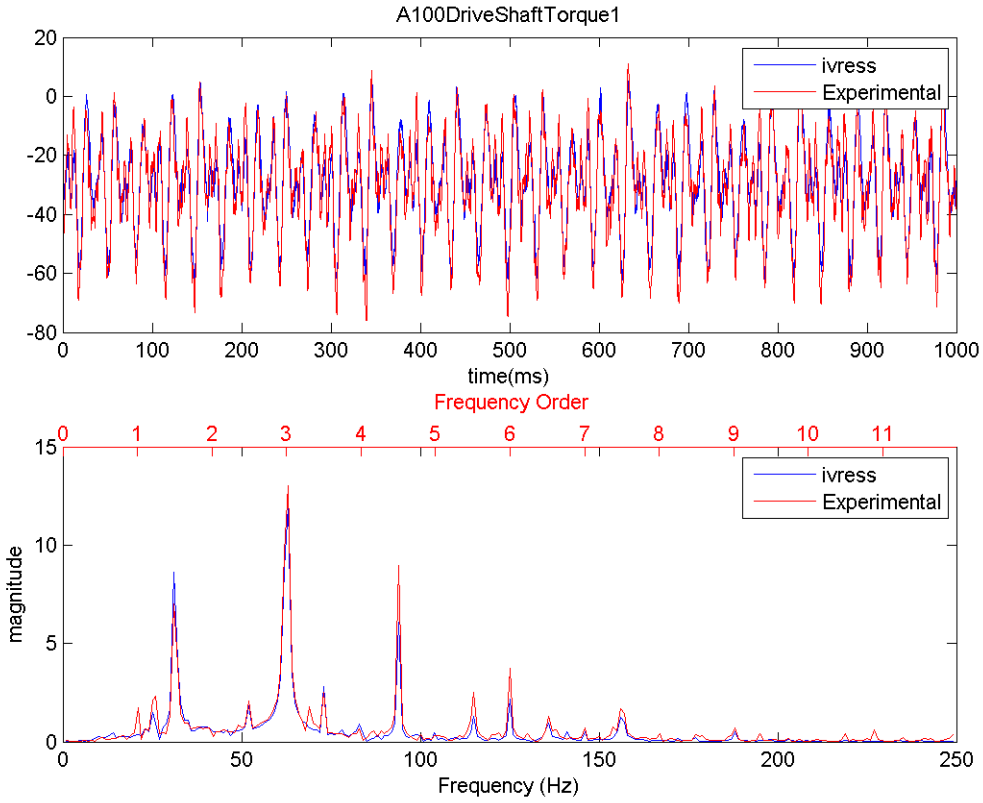

Figure 57 Drive shaft torque in the A100 operation range with belt axial stiffness (EA) = 110,000 N instead of 140,563 N in the base line

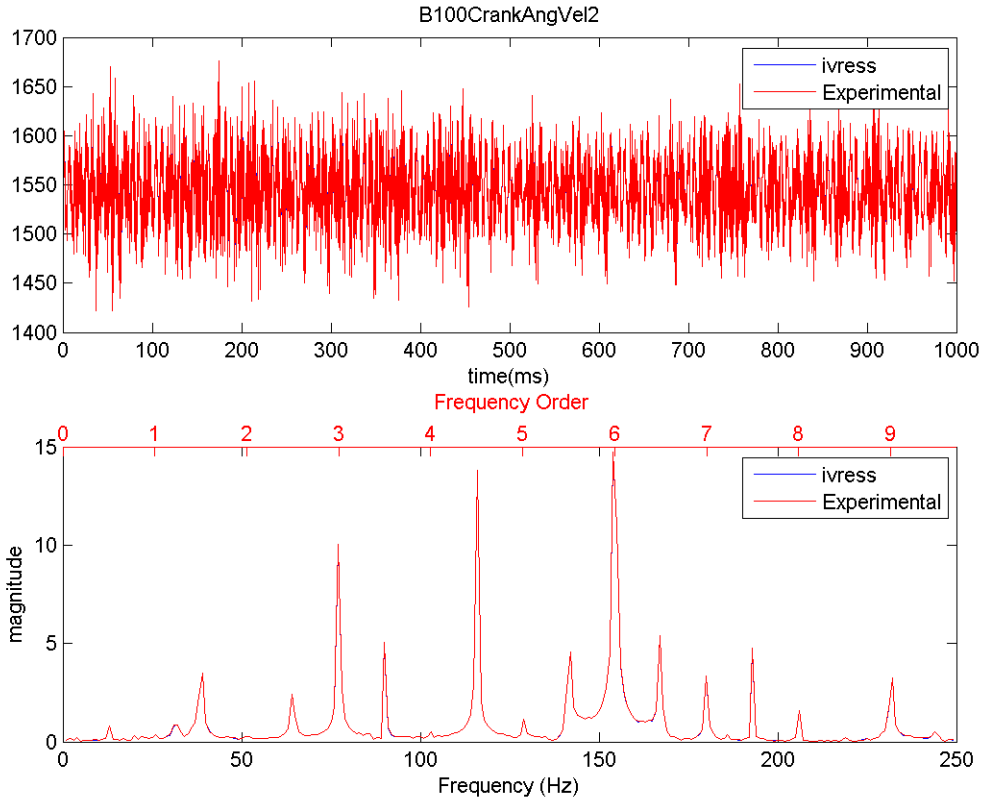

Figure 58 Crankshaft angular velocity in the B100 operation range with belt axial stiffness (EA) = 110,000 N instead of 140,563 N in the base line

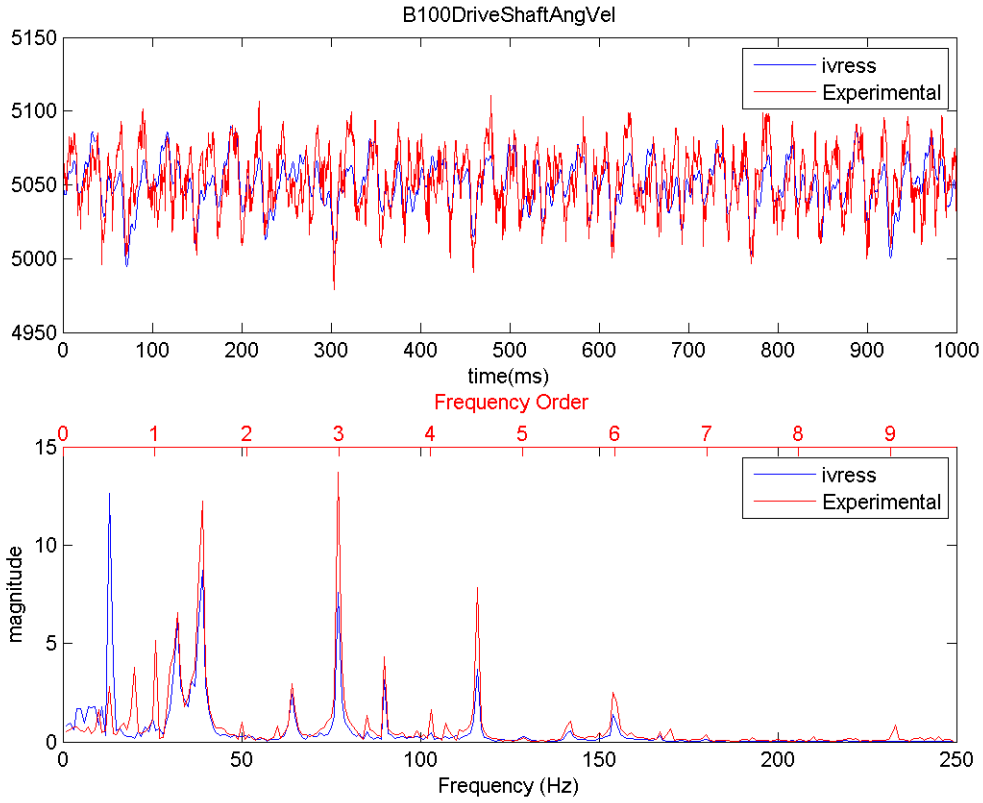

Figure 59 Drive shaft angular velocity in the B100 operation range with belt axial stiffness (EA) = 110,000 N instead of 140,563 N in the base line

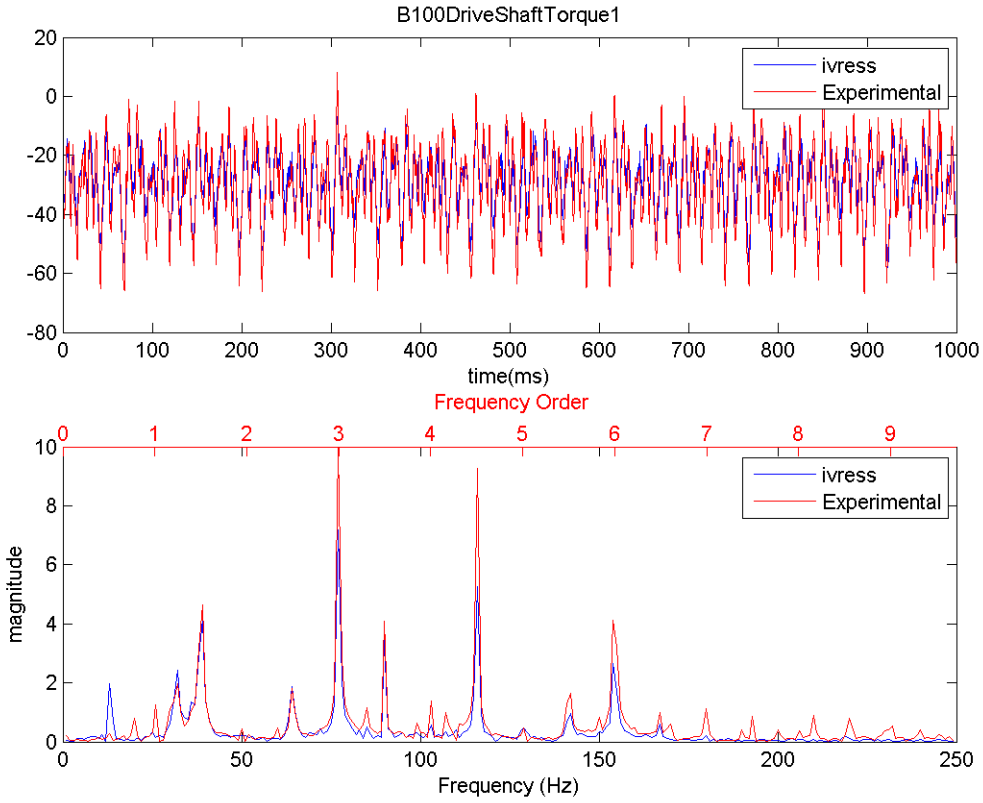

Figure 60 Drive shaft angular velocity in the B100 operation range with belt axial stiffness (EA) = 110,000 N instead of 140,563 N in the base line

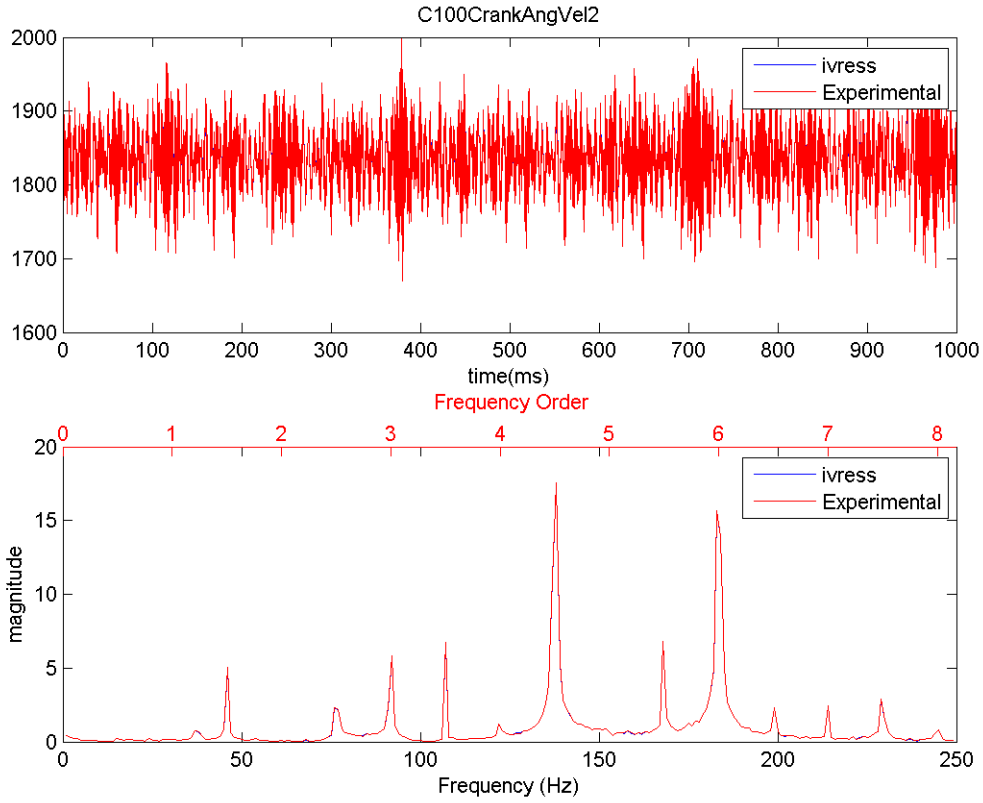

Figure 61 Crankshaft angular velocity in the C100 operation range with belt axial stiffness (EA) = 110,000 N instead of 140,563 N in the base line

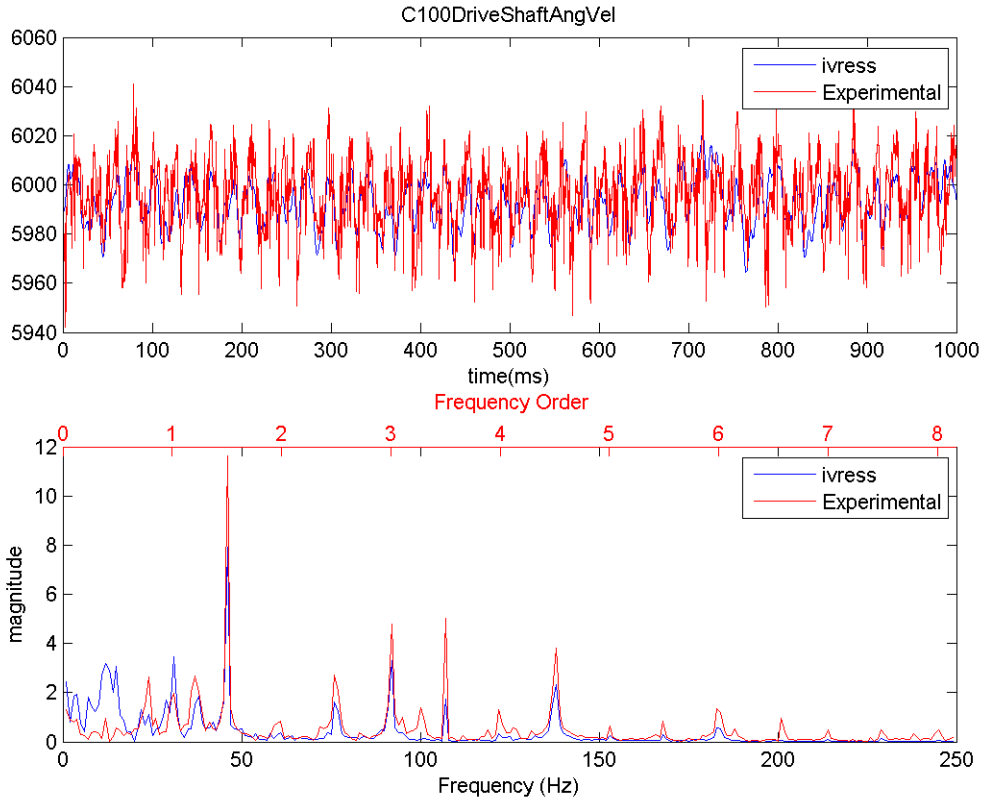

Figure 62 Drive shaft angular velocity in the C100 operation range with belt axial stiffness (EA) = 110,000 N instead of 140,563 N in the base line

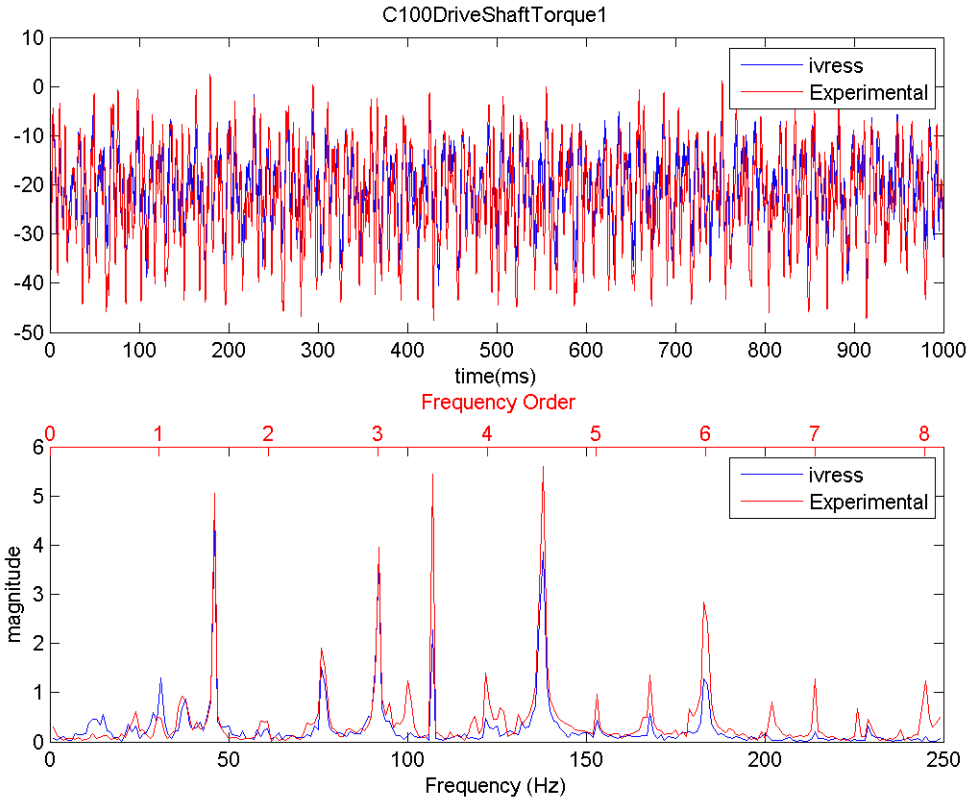

Figure 63 Drive shaft torque in the C100 operation range with belt axial stiffness (EA) = 110,000 N instead of 140,563 N in the base line

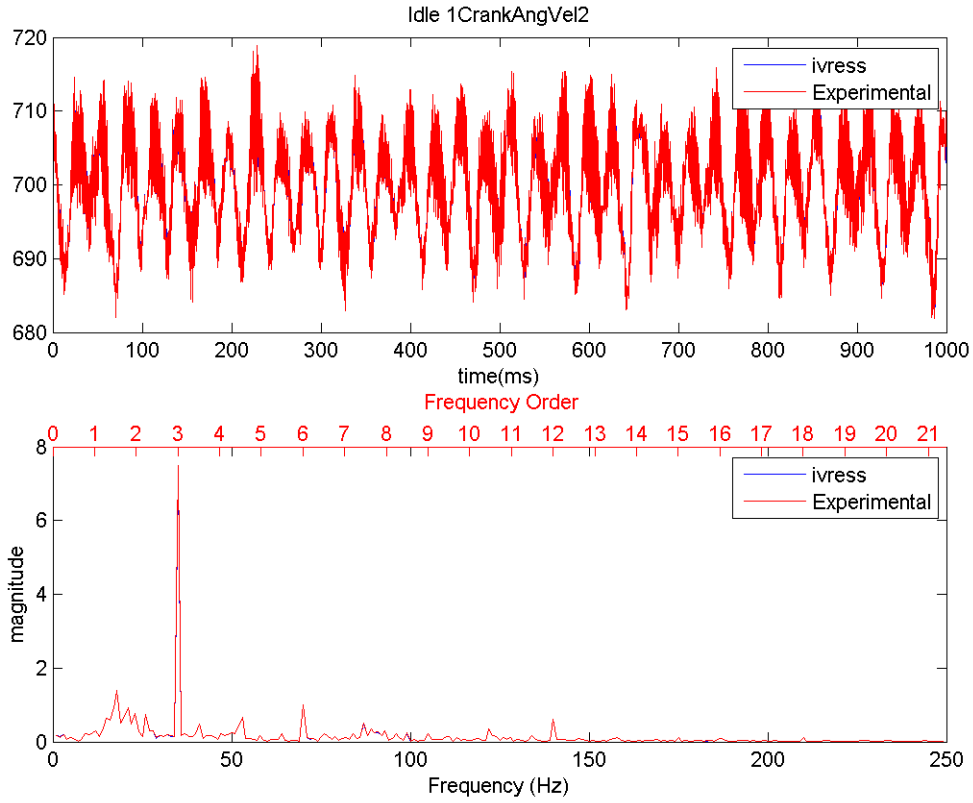

Figure 64 Crankshaft angular velocity in the idle operation range with belt axial stiffness (EA) = 110,000 N instead of 140,563 N in the base line

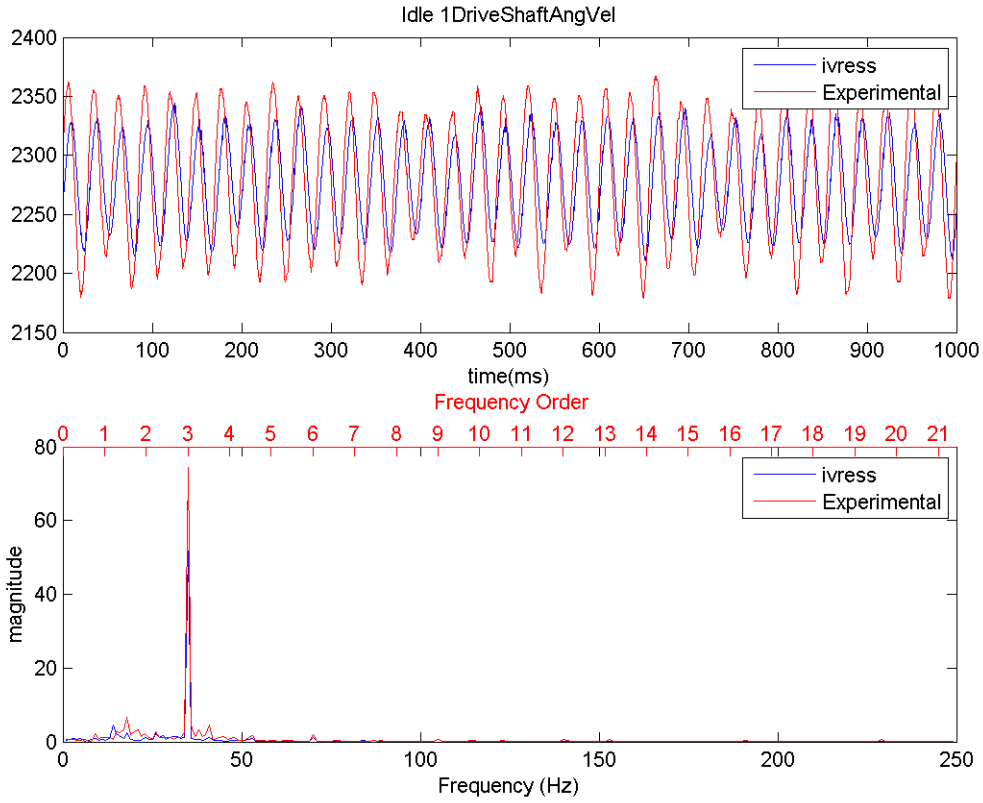

Figure 65 Drive shaft angular velocity in the idle operation range with belt axial stiffness (EA) = 110,000 N instead of 140,563 N in the base line

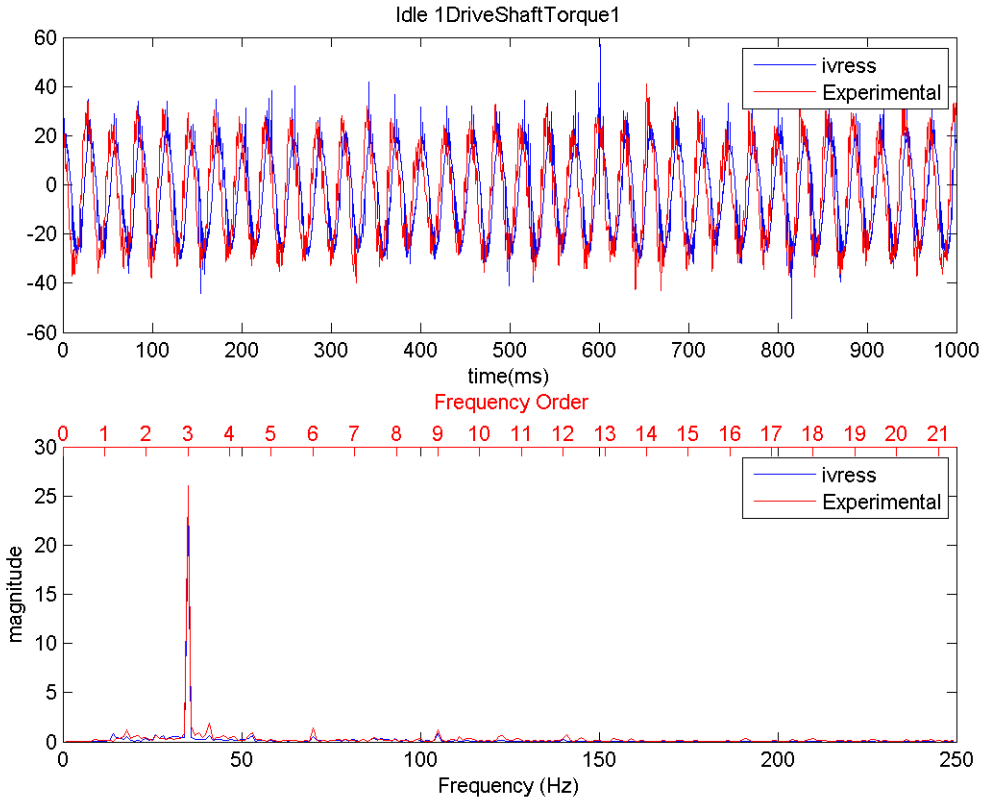

Figure 66 Drive shaft torque in the idle operation range with belt axial stiffness (EA) = 110,000 N instead of 140,563 N in the base line

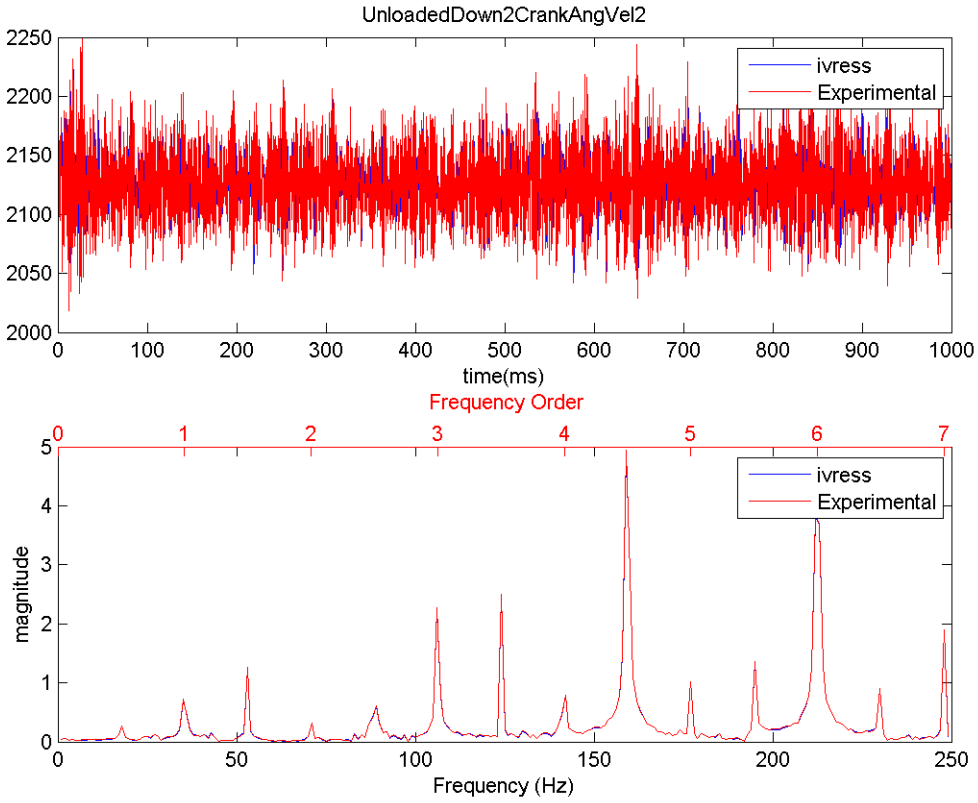

Figure 67 Crankshaft angular velocity in the UnloadedDown operation range with belt axial stiffness (EA) = 110,000 N instead of 140,563 N in the base line

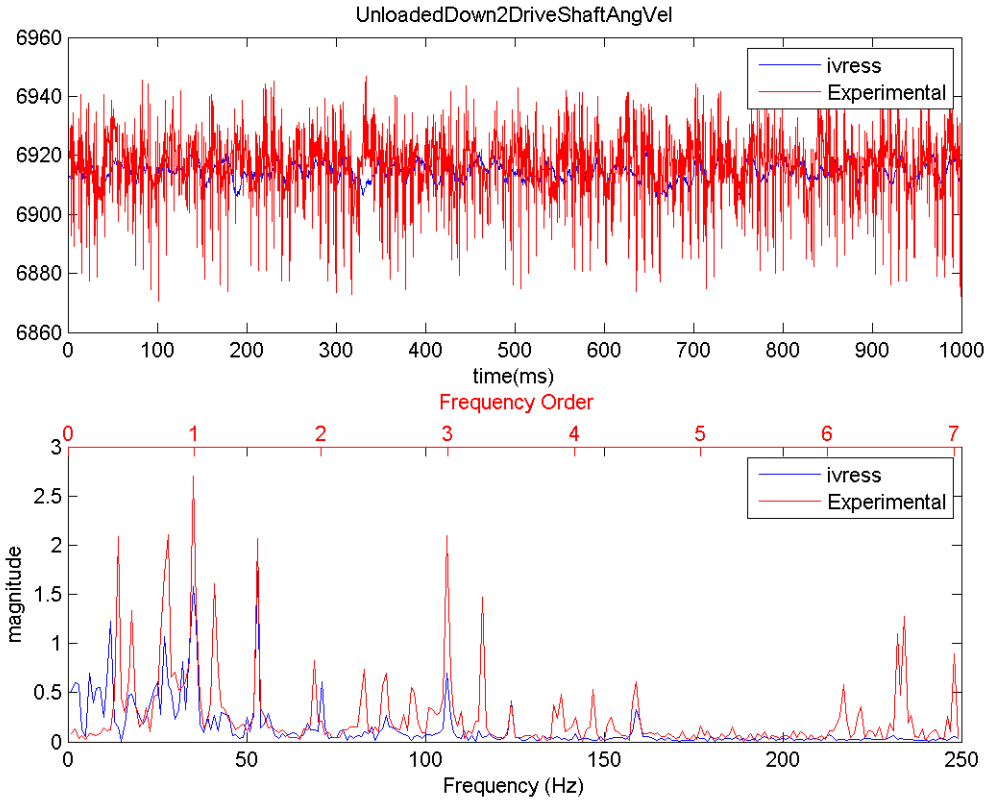

Figure 68 Drive shaft angular velocity in the UnloadedDown operation range with belt axial stiffness (EA) = 110,000 N instead of 140,563 N in the base line

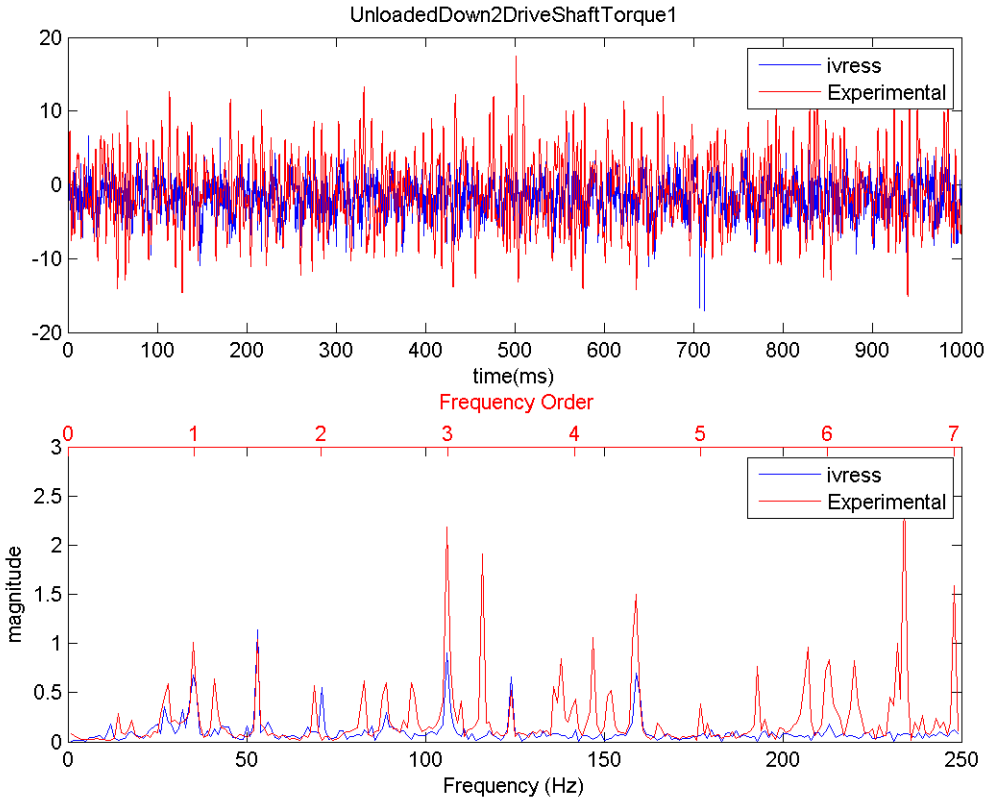

Figure 69 Drive shaft torque in the UnloadedDown operation range with belt axial stiffness (EA) = 110,000 N instead of 140,563 N in the base line

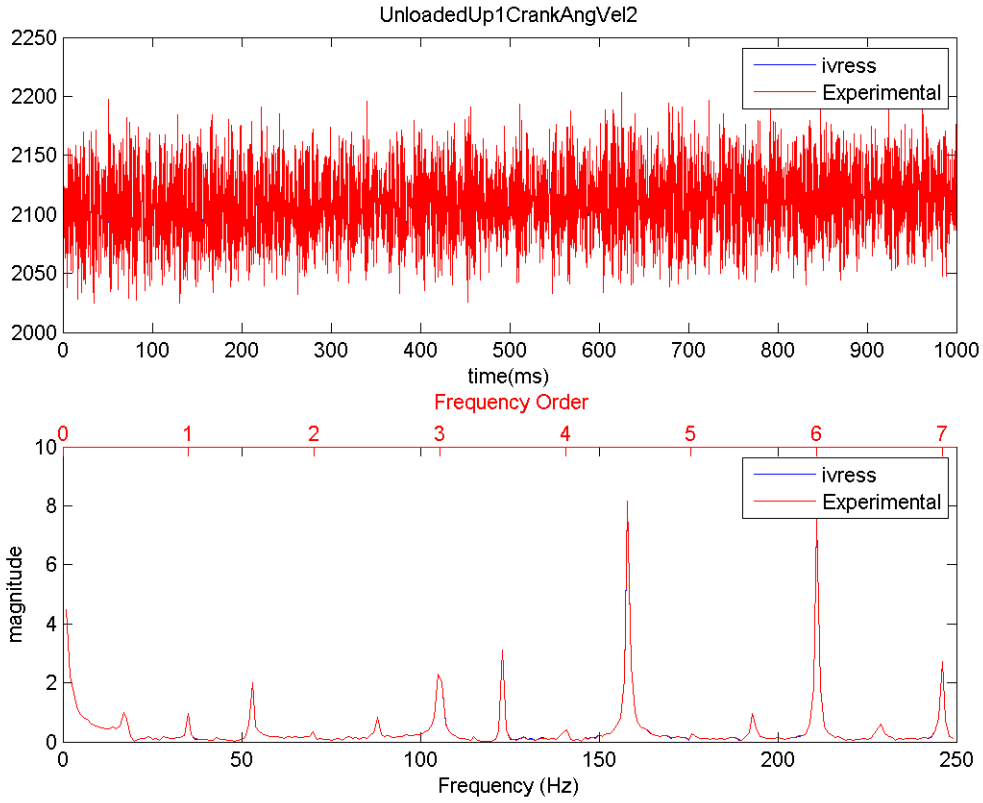

Figure 70 Crankshaft angular velocity in the UnloadedUp operation range with belt axial stiffness (EA) = 110,000 N instead of 140,563 N in the base line

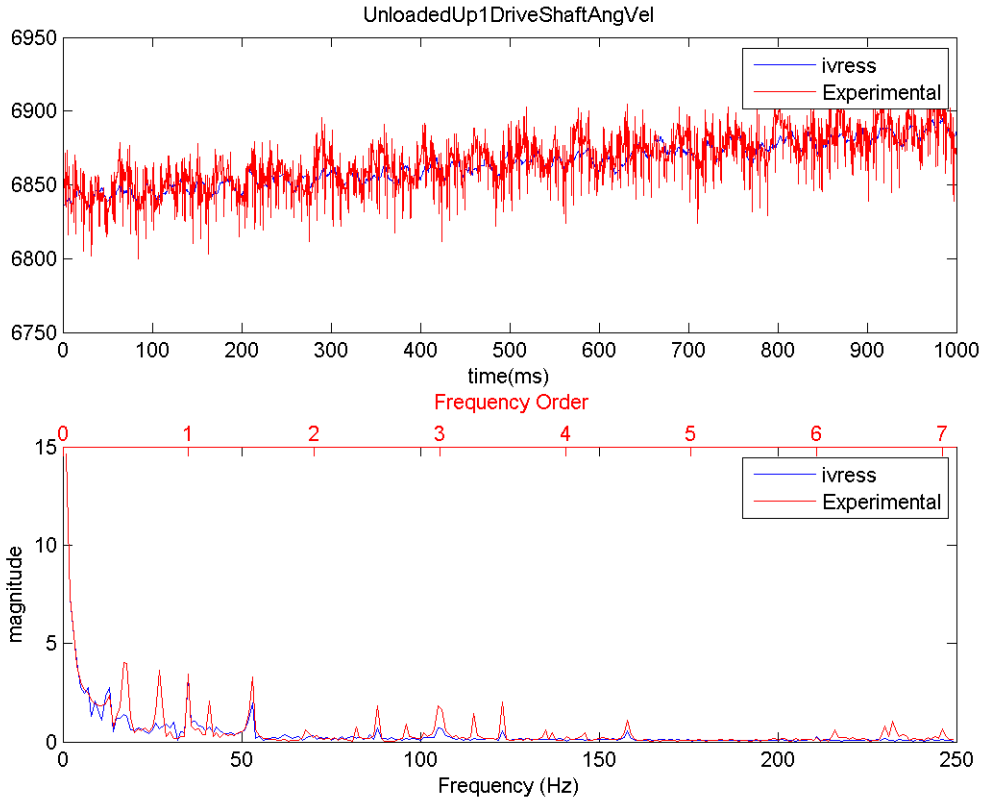

Figure 71 Drive shaft angular velocity in the UnloadedUp operation range with belt axial stiffness (EA) = 110,000 N instead of 140,563 N in the base line

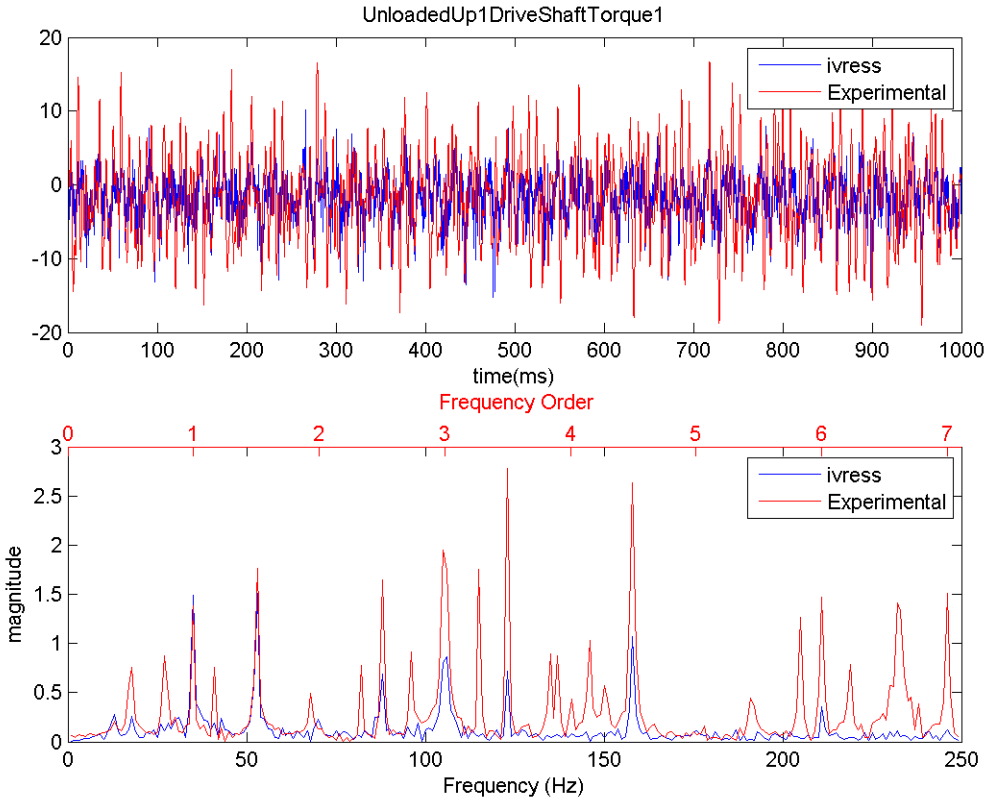

Figure 72 Drive shaft torque in the UnloadedUp operation range with belt axial stiffness (EA) = 110,000 N instead of 140,563 N in the base line

5 Belt Bending Damping increases to $10 \times 10^{-5}\ N.m^2.s$ instead of $5 \times 10^{-5}\ N.m^2.s$ in The Base Line

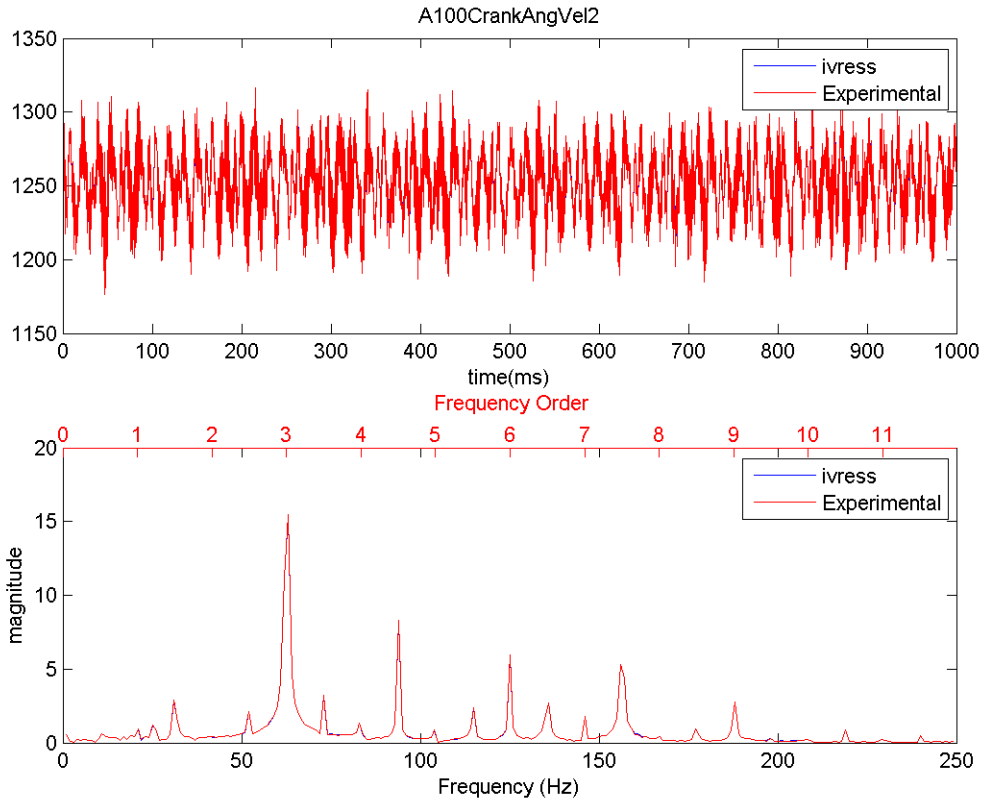

Figure 73 Crankshaft angular velocity in the A100 operation range with belt bending damping = $10 \times 10^{-5}\ N.m^2.s$ instead of $5 \times 10^{-5}\ N.m^2.s$ in the base line

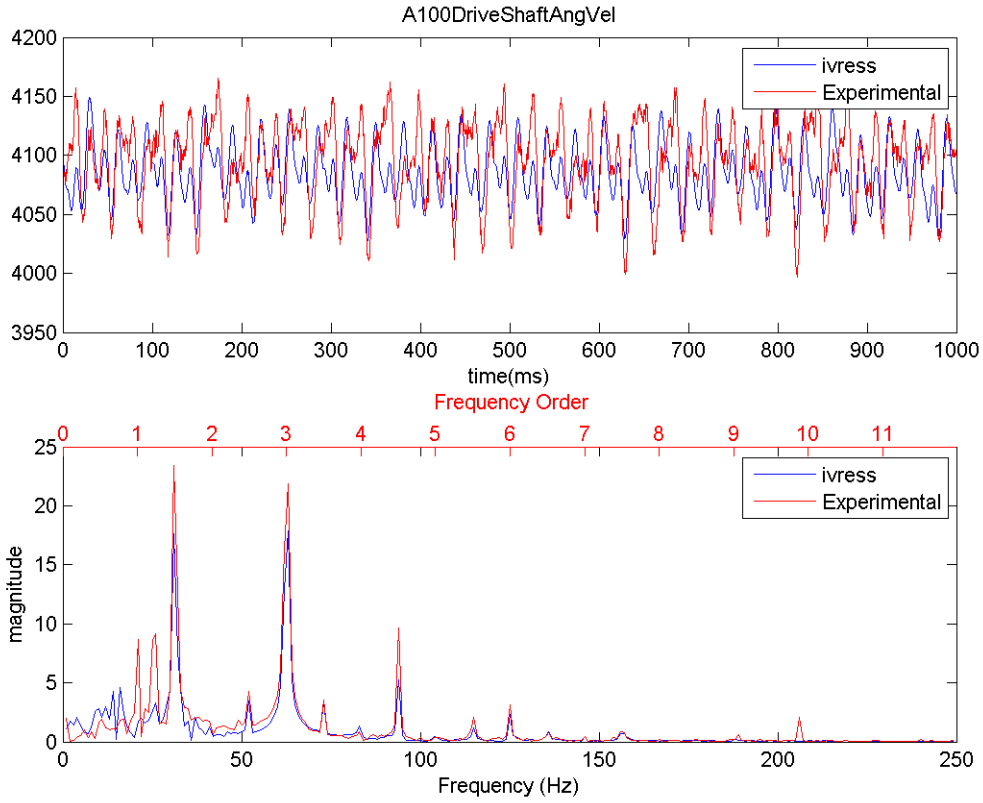

Figure 74 Drive shaft angular velocity in the A100 operation with belt bending damping $= 10 \times 10^{-5}\ N.m^2.s$ instead of $5 \times 10^{-5}\ N.m^2.s$ in the base line

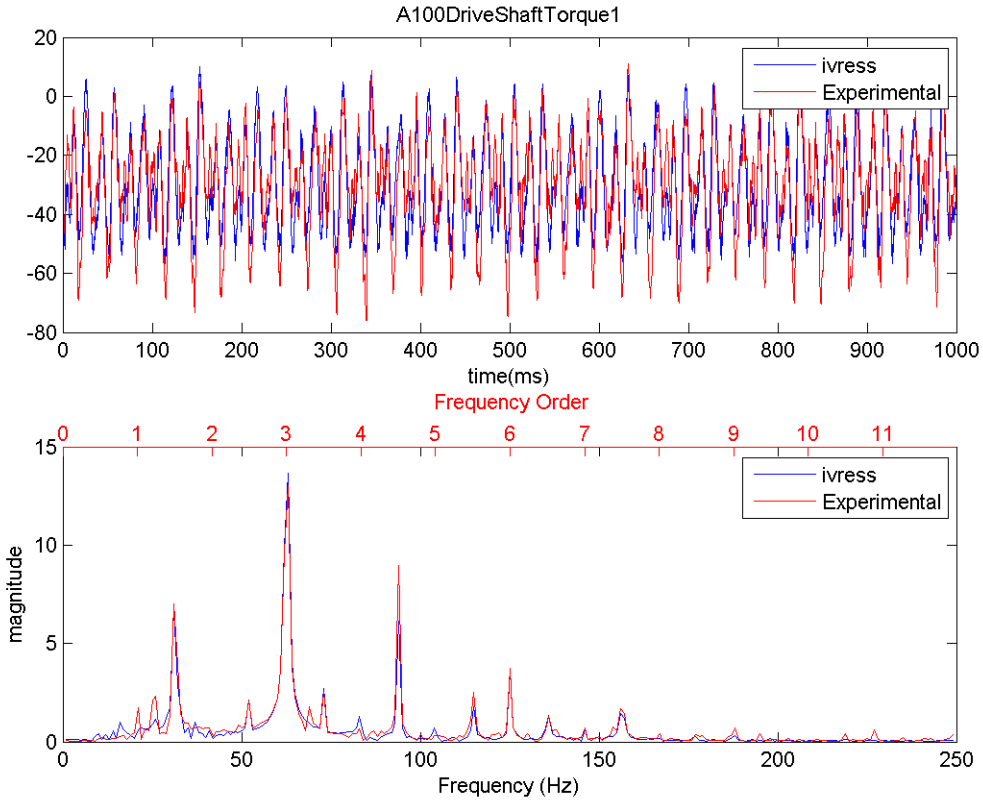

Figure 75 Drive shaft torque in the A100 operation range with belt bending damping $= 10 \times 10^{-5}\ N.m^2.s$ instead of $5 \times 10^{-5}\ N.m^2.s$ in the base line

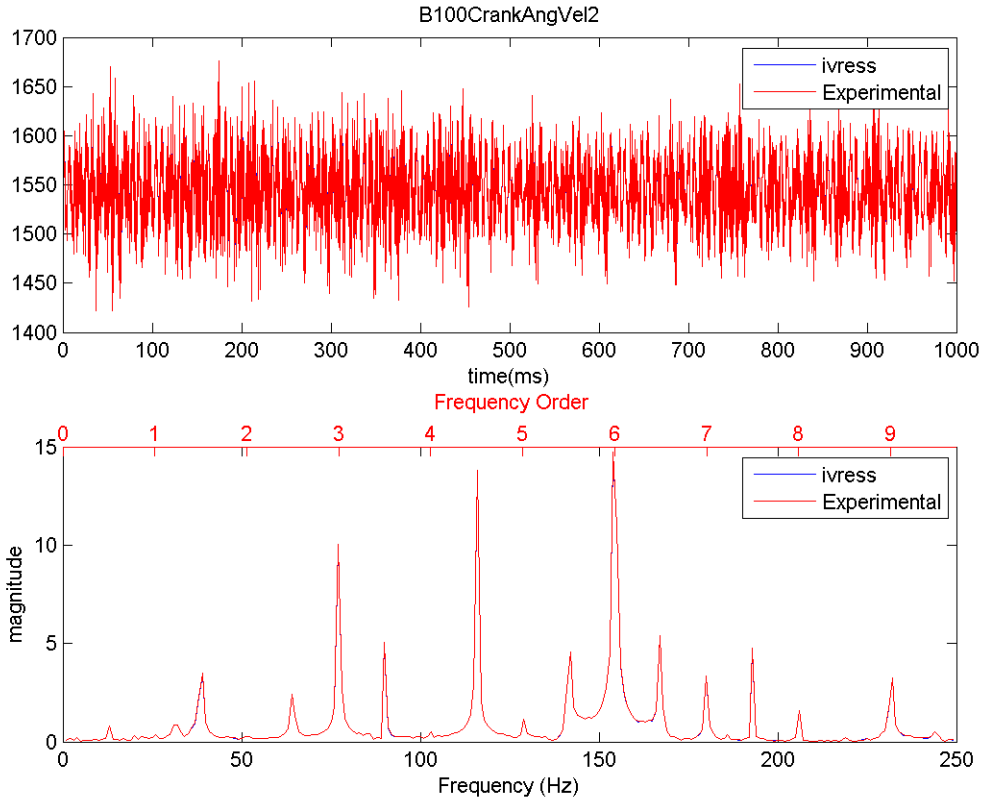

Figure 76 Crankshaft angular velocity in the B100 operation range with belt bending damping = $10 \times 10^{-5}\ N.m^2.s$ instead of $5 \times 10^{-5}\ N.m^2.s$ in the base line

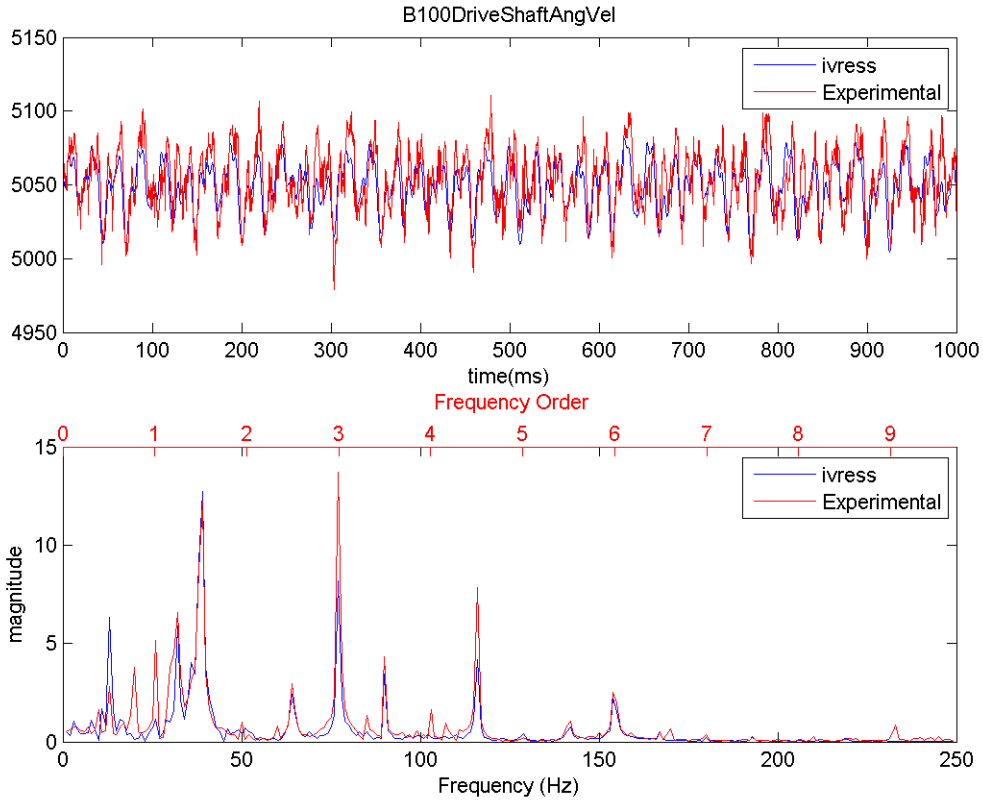

Figure 77 Drive shaft angular velocity in the B100 operation range with belt bending damping = $10 \times 10^{-5}\ N.m^2.s$ instead of $5 \times 10^{-5}\ N.m^2.s$ in the base line

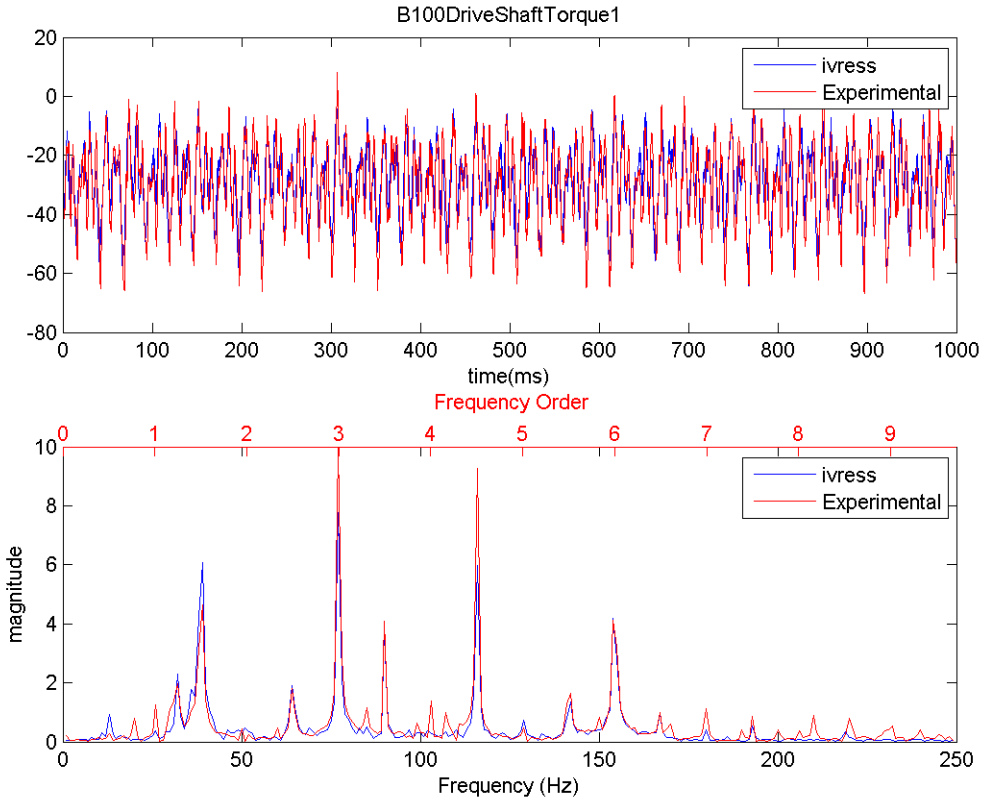

Figure 78 Drive shaft torque in the B100 operation range with belt bending damping $= 10 \times 10^{-5}\ N.m^2.s$ instead of $5 \times 10^{-5}\ N.m^2.s$ in the base line

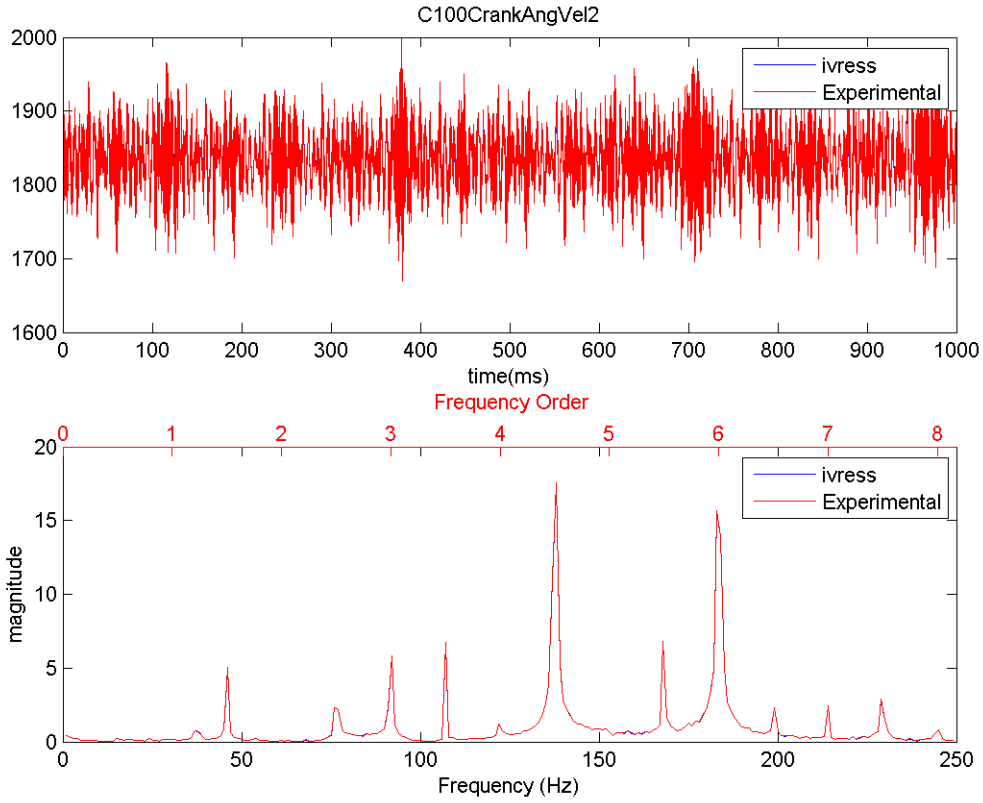

Figure 79 Crankshaft angular velocity in the A100 operation range with belt bending damping = $10 \times 10^{-5}\ N.m^2.s$ instead of $5 \times 10^{-5}\ N.m^2.s$ in the base line

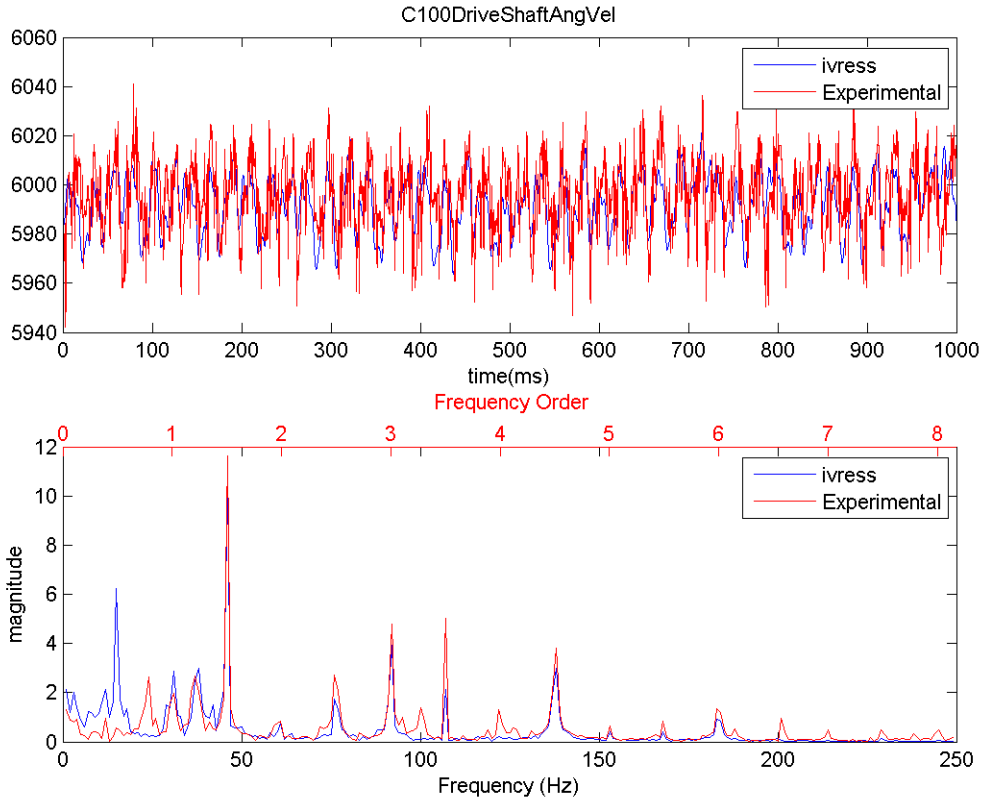

Figure 80 Drive shaft angular velocity in the C100 operation range with belt bending damping = $10 \times 10^{-5}\ N.m^2.s$ instead of $5 \times 10^{-5}\ N.m^2.s$ in the base line

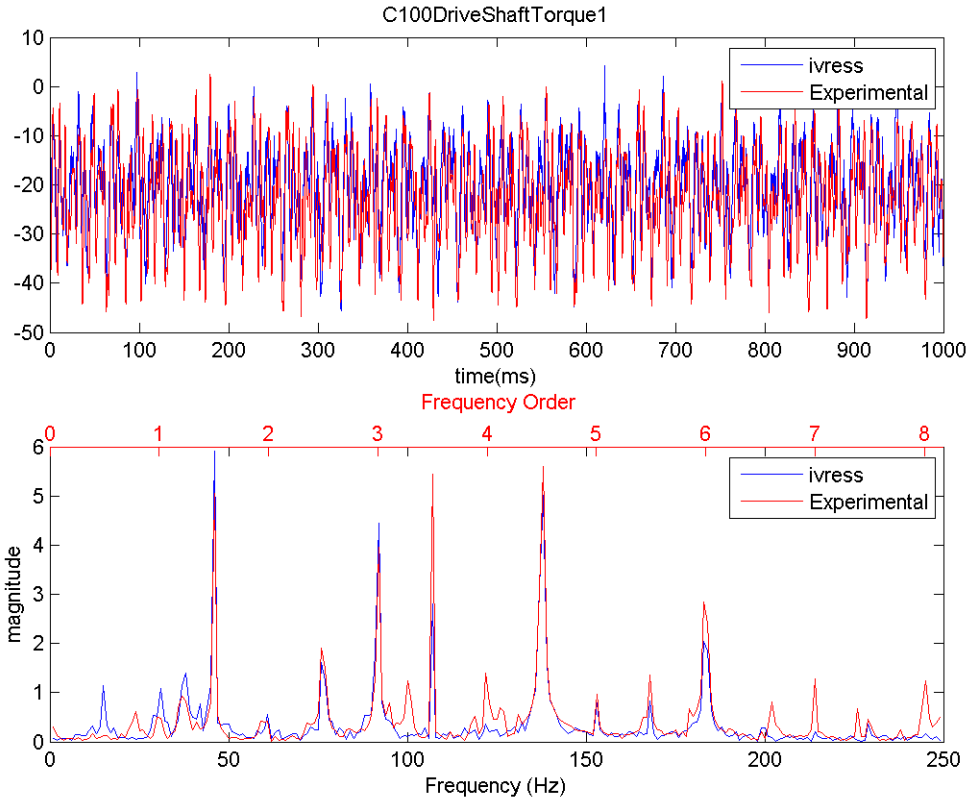

Figure 81 Drive shaft torque in the C100 operation range with belt bending damping $= 10 \times 10^{-5}\ N.m^2.s$ instead of $5 \times 10^{-5}\ N.m^2.s$ in the base line

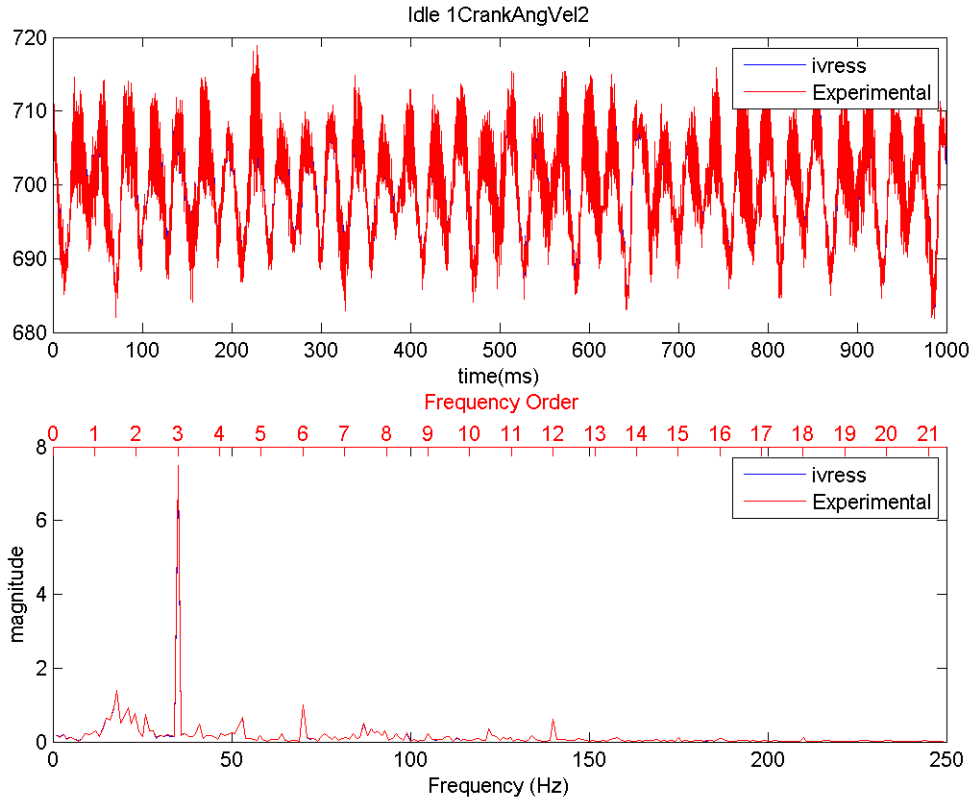

Figure 82 Crankshaft angular velocity in the idle operation range with belt bending damping = $10 \times 10^{-5}\ N.m^2.s$ instead of $5 \times 10^{-5}\ N.m^2.s$ in the base line

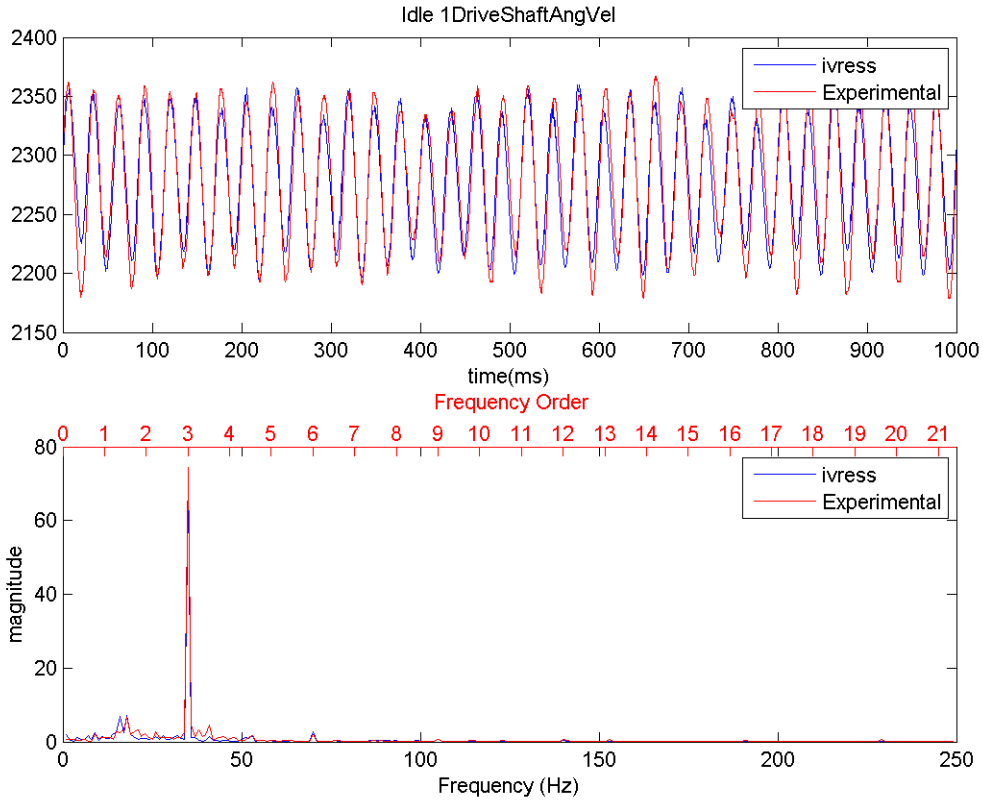

Figure 83 Drive shaft angular velocity in the idle operation range with belt bending damping = $10 \times 10^{-5}\ N.m^2.s$ instead of $5 \times 10^{-5}\ N.m^2.s$ in the base line

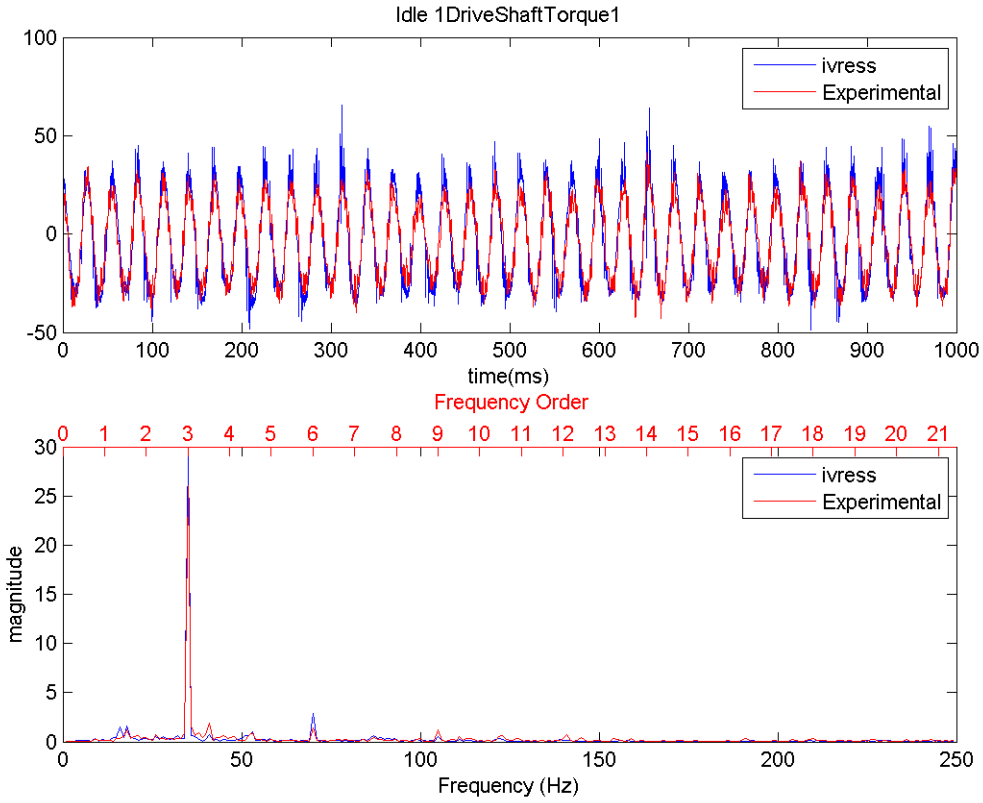

Figure 84 Drive shaft torque in the idle operation range with belt bending damping $= 10 \times 10^{-5}\ N.m^2.s$ instead of $5 \times 10^{-5}\ N.m^2.s$ in the base line

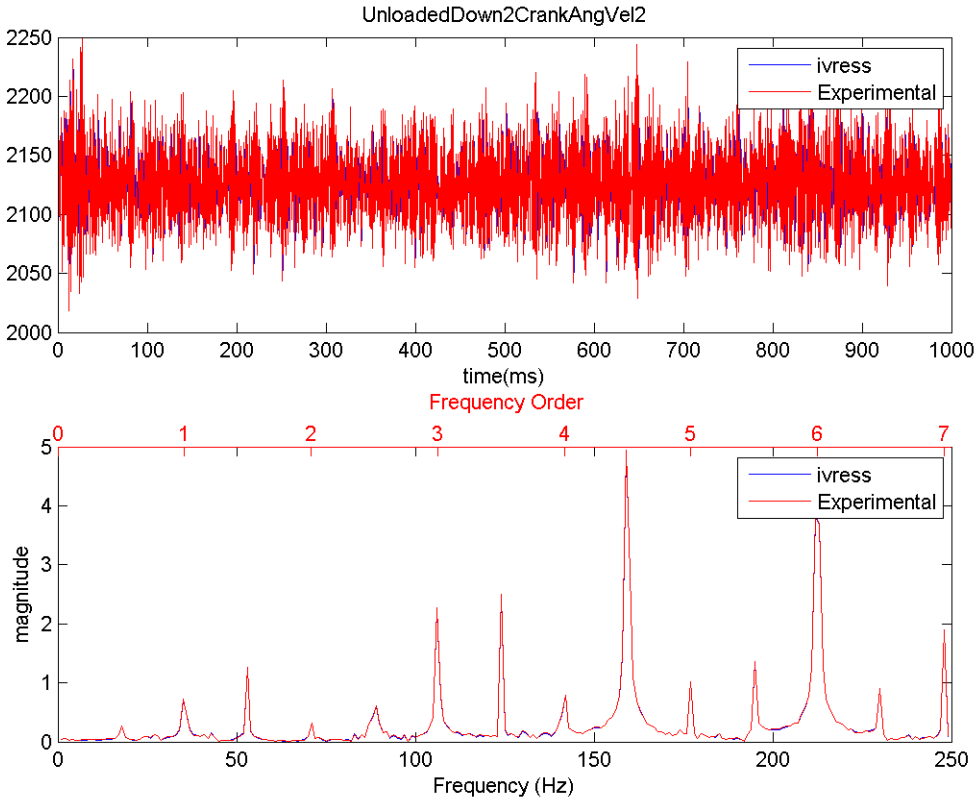

Figure 85 Crankshaft angular velocity in the UnloadedDown operation range with belt bending damping = $10 \times 10^{-5}\ N.m^2.s$ instead of $5 \times 10^{-5}\ N.m^2.s$ in the base line

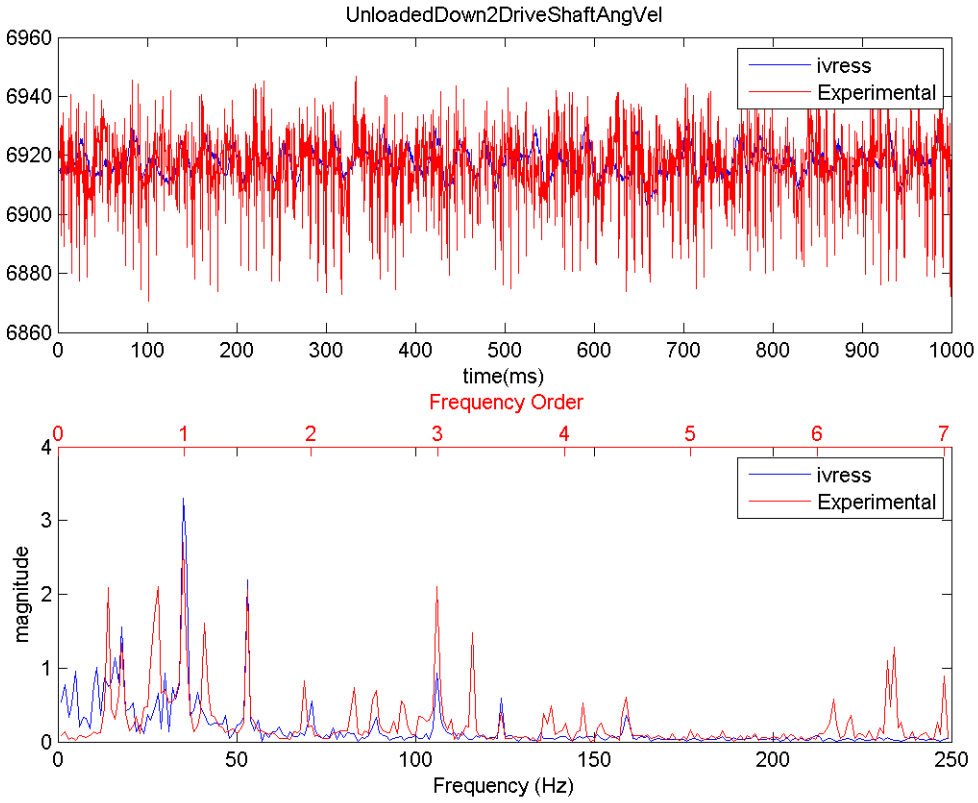

Figure 86 Drive shaft angular velocity in the UnloadedDown operation range with belt bending damping = $10 \times 10^{-5}\ N.m^2.s$ instead of $5 \times 10^{-5}\ N.m^2.s$ in the base line

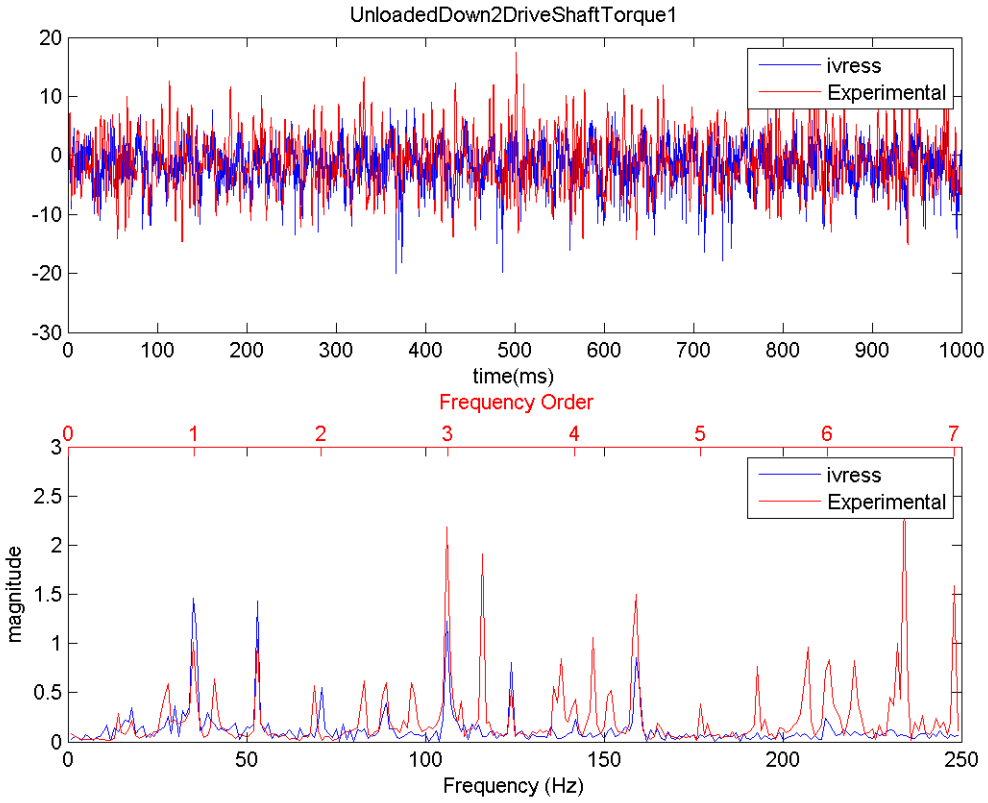

Figure 87 Drive shaft torque in the UnloadedDown operation range with belt bending damping = $10 \times 10^{-5}\ N.m^2.s$ instead of $5 \times 10^{-5}\ N.m^2.s$ in the base line

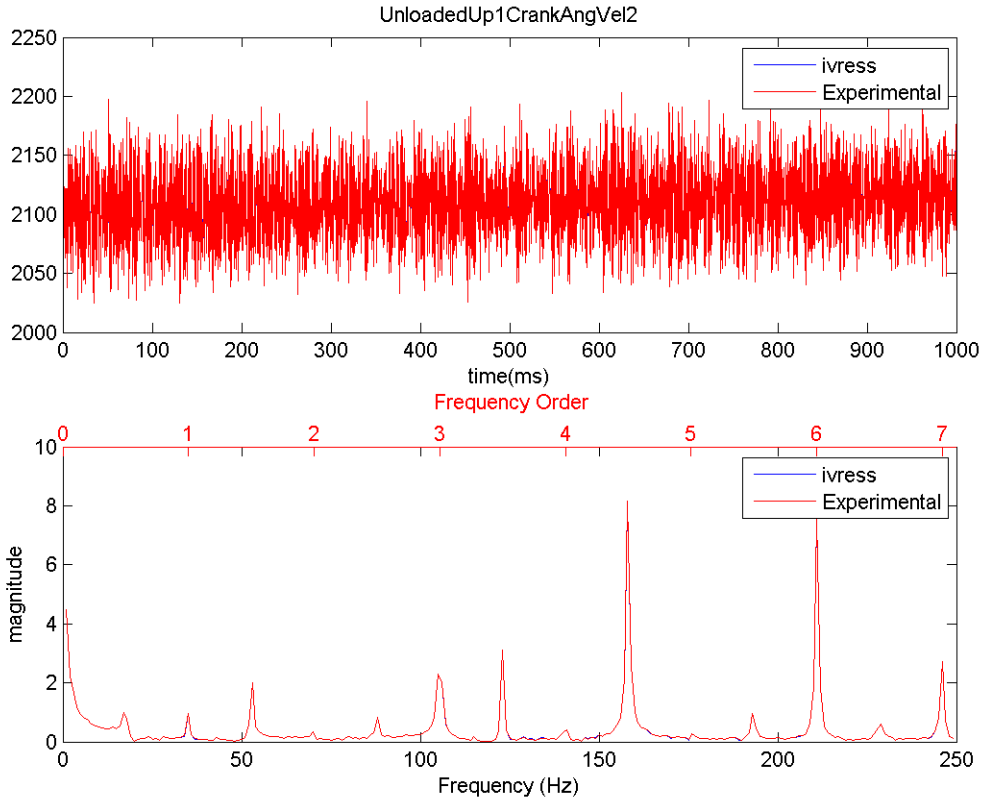

Figure 88 Crankshaft angular velocity in the UnloadedUp operation range with belt bending damping = $10 \times 10^{-5}\ N.m^2.s$ instead of $5 \times 10^{-5}\ N.m^2.s$ in the base line

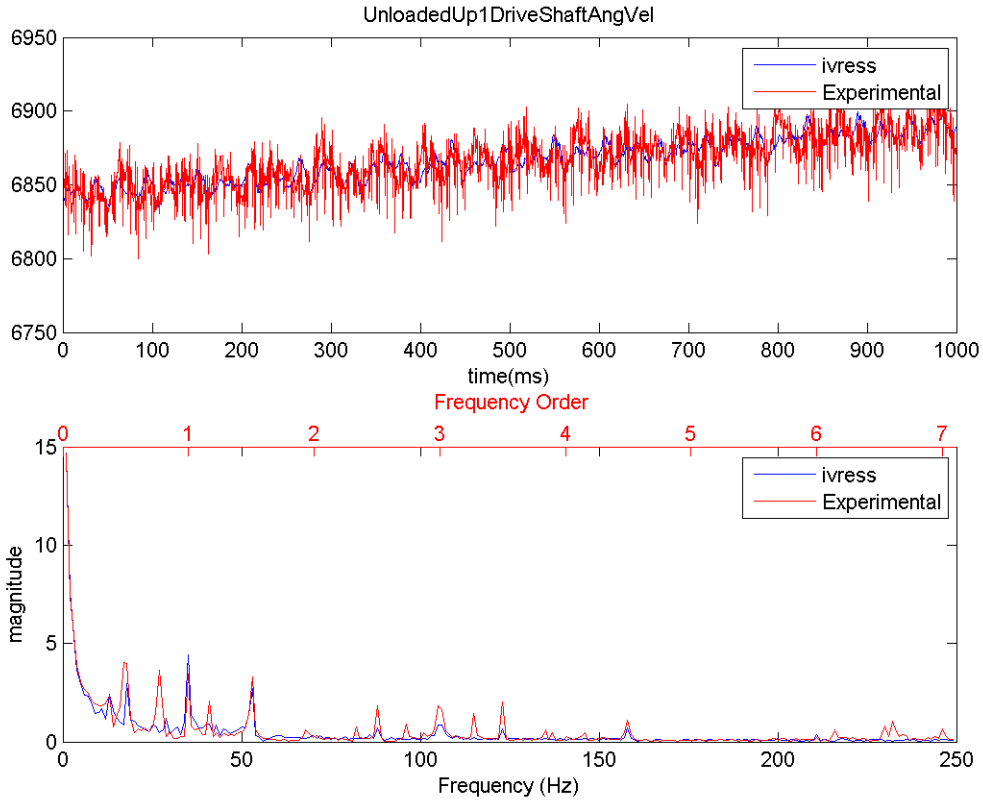

Figure 89 Drive shaft angular velocity in the UnloadedUp operation range with belt bending damping = $10 \times 10^{-5}\ N.m^2.s$ instead of $5 \times 10^{-5}\ N.m^2.s$ in the base line

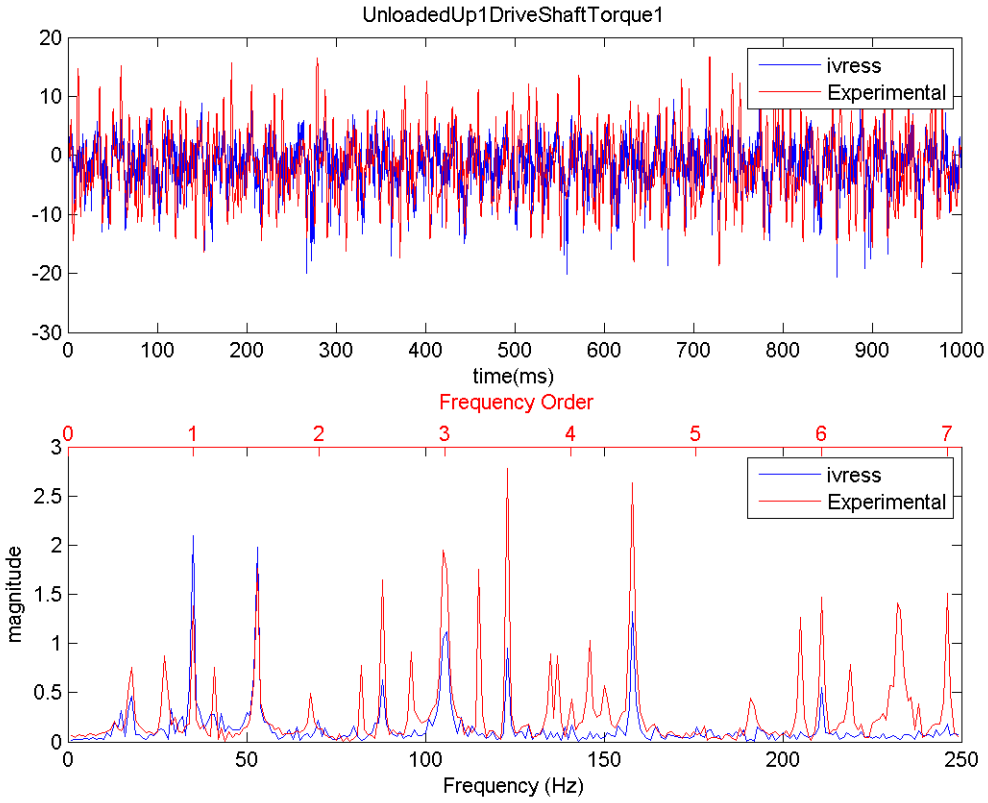

Figure 90 Drive shaft torque in the UnloadedUp operation range with belt bending damping = $10 \times 10^{-5}\ N.m^2.s$ instead of $5 \times 10^{-5}\ N.m^2.s$ in the base line

6 Belt Bending Stiffness Increases To 2 $N.m^2$ Instead Of 0 $N.m^2$ In The Base Line

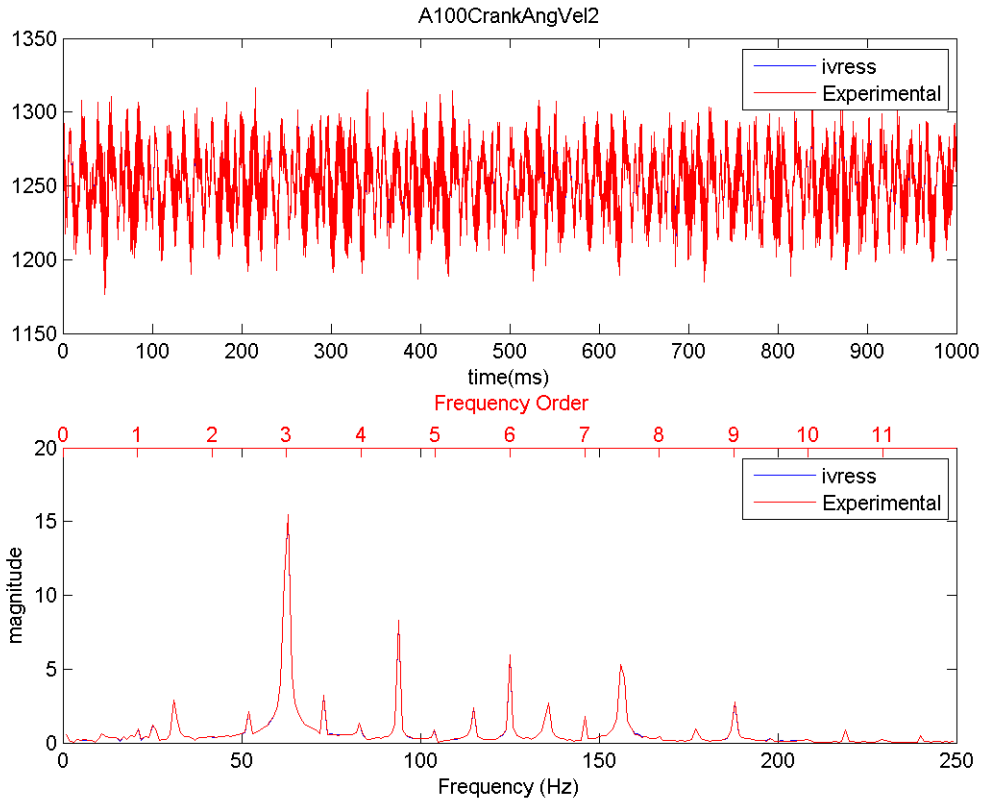

Figure 91 Crankshaft angular velocity in the A100 operation range with belt bending stiffness increases to 2 $N.m^2$ instead of 0 $N.m^2$in the base line

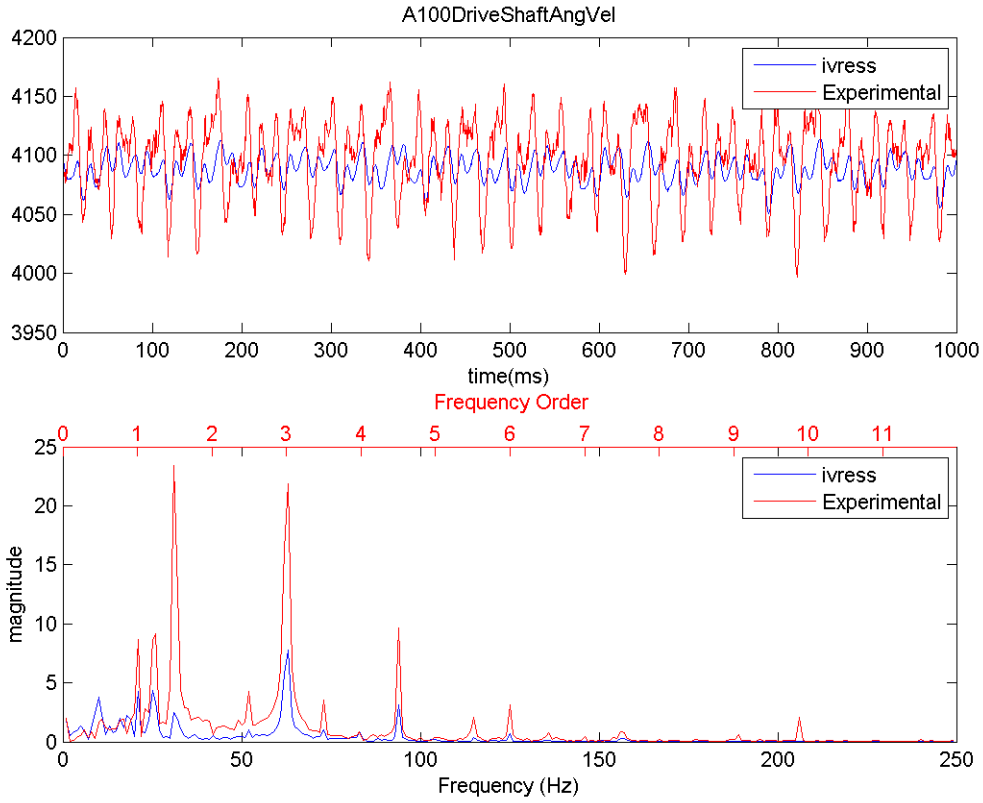

Figure 92 Drive shaft angular velocity in the A100 operation range with belt bending stiffness increases to 2 $N.m^2$ instead of 0 $N.m^2$in the base line

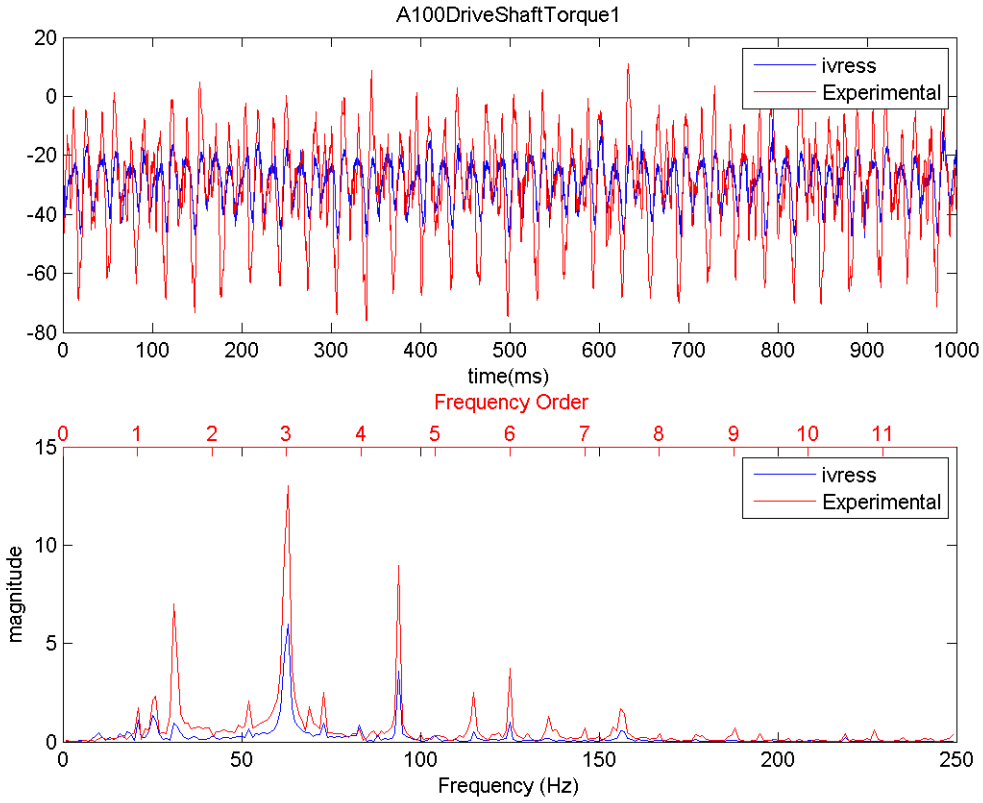

Figure 93 Drive shaft torque in the A100 operation range with bending stiffness increases to 2 $N.m^2$ instead of 0 $N.m^2$in the base line

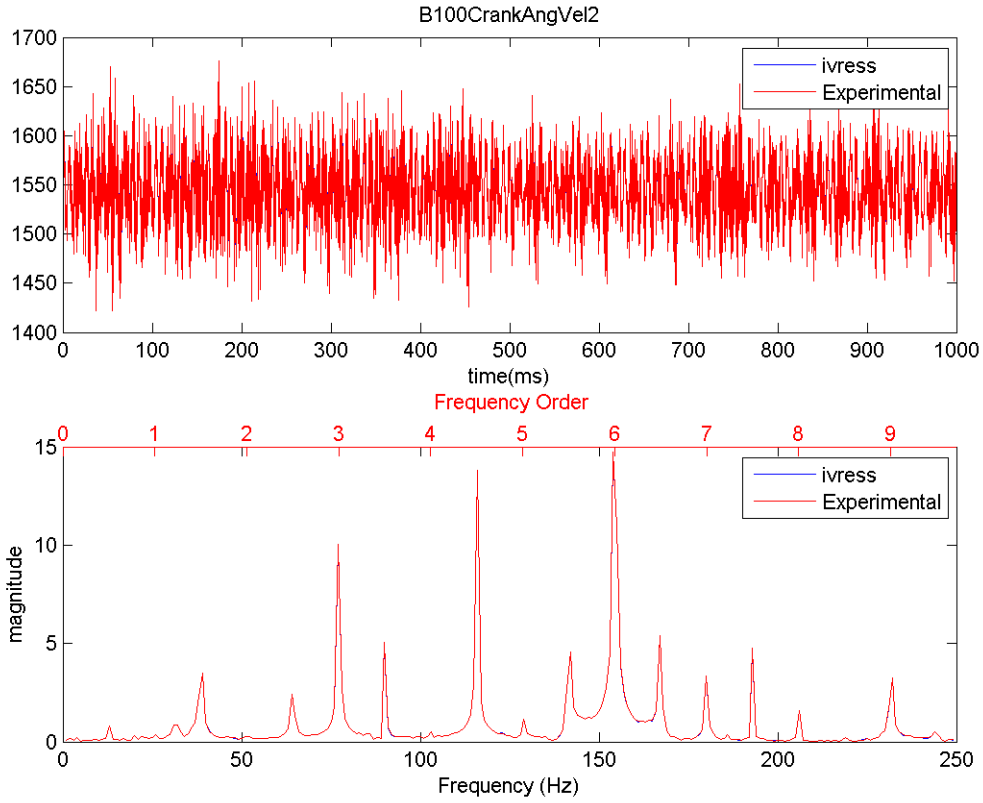

Figure 94 Crankshaft angular velocity in the B100 operation range with belt bending stiffness increases to 2 $N.m^2$ instead of 0 $N.m^2$in the base line

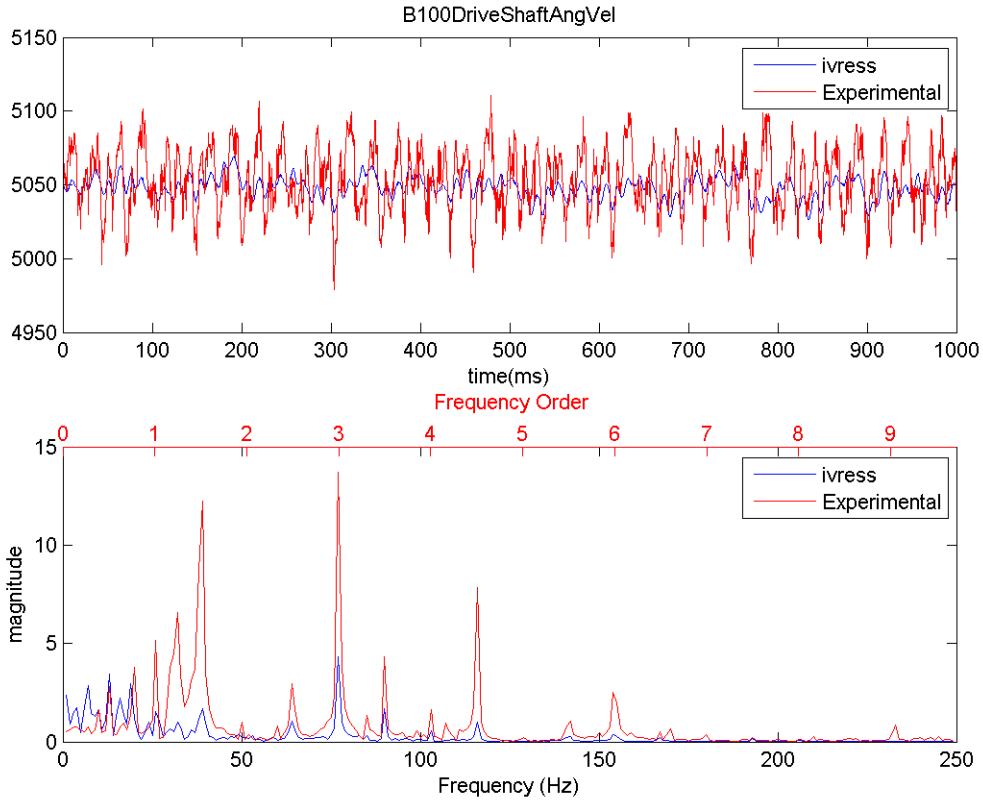

Figure 95 Drive shaft angular velocity in the B100 operation range with belt bending stiffness increases to 2 $N.m^2$ instead of 0 $N.m^2$in the base line

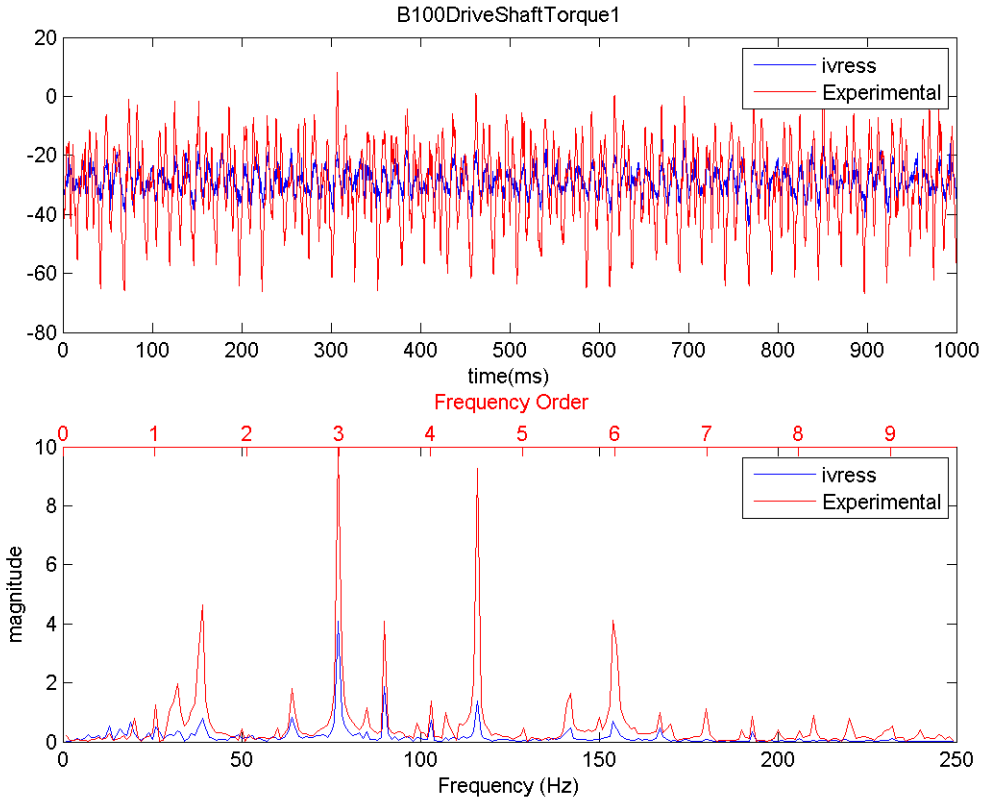

Figure 96 Drive shaft torque in the B100 operation range with bending stiffness increases to 2 $N.m^2$ instead of 0 $N.m^2$in the base line

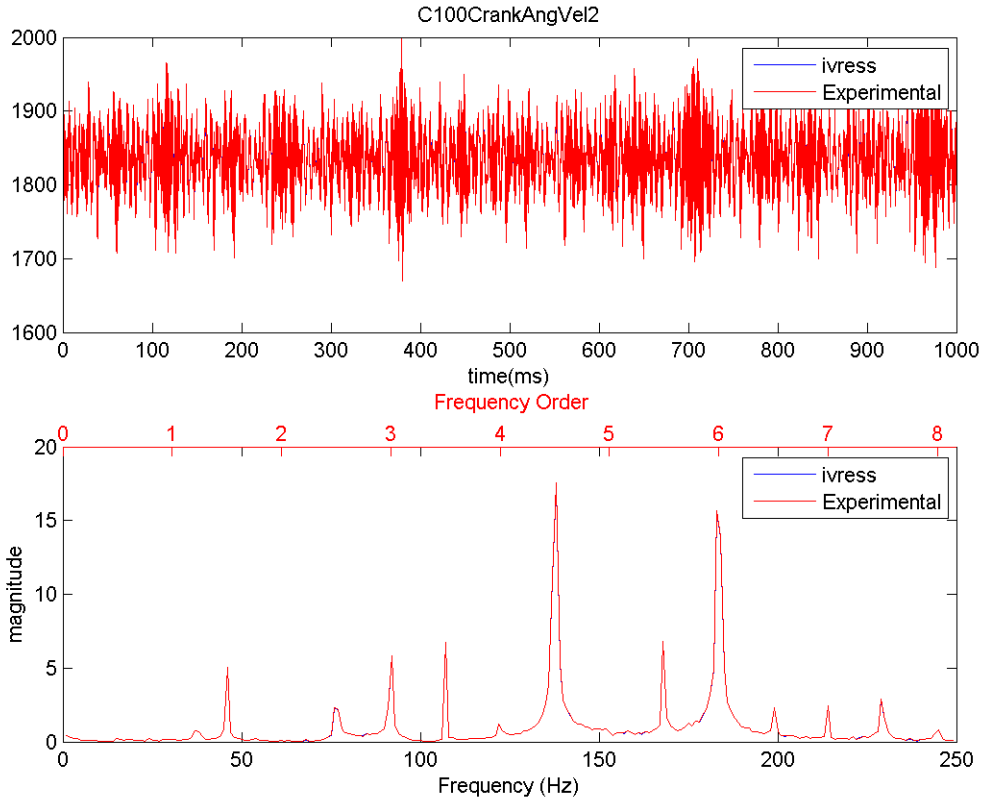

Figure 97 Crankshaft angular velocity in the C100 operation range with belt bending stiffness increases to 2 $N.m^2$ instead of 0 $N.m^2$in the base line

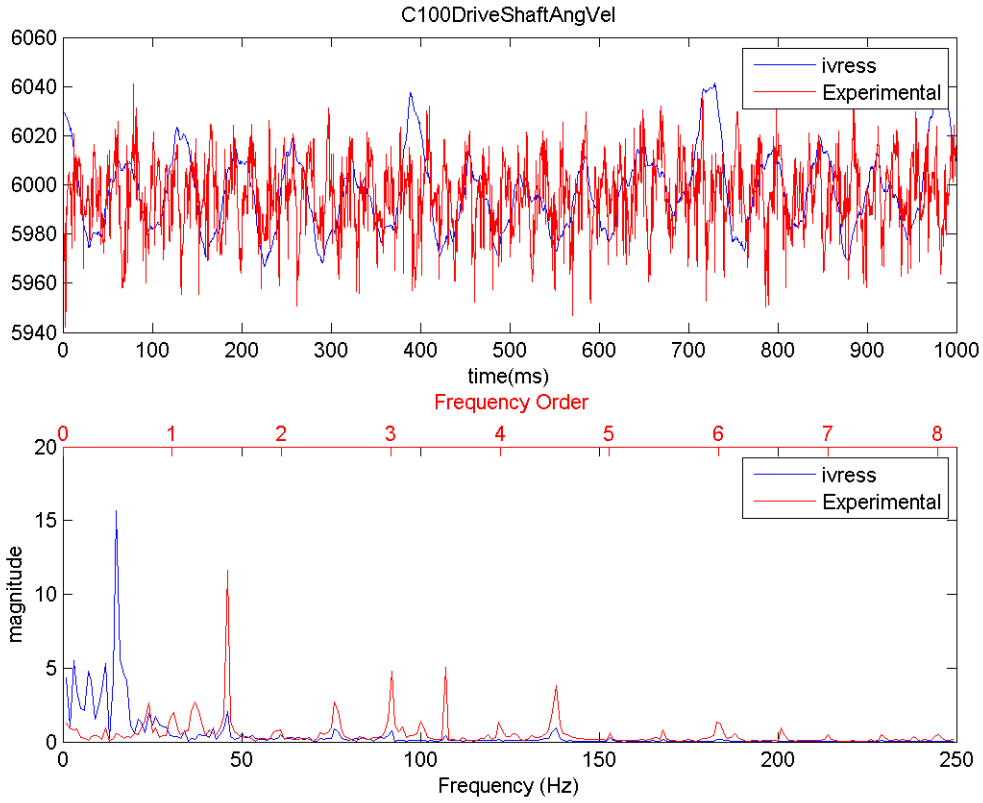

Figure 98 Drive shaft angular velocity in the C100 operation range with belt bending stiffness increases to 2 $N.m^2$ instead of 0 $N.m^2$in the base line

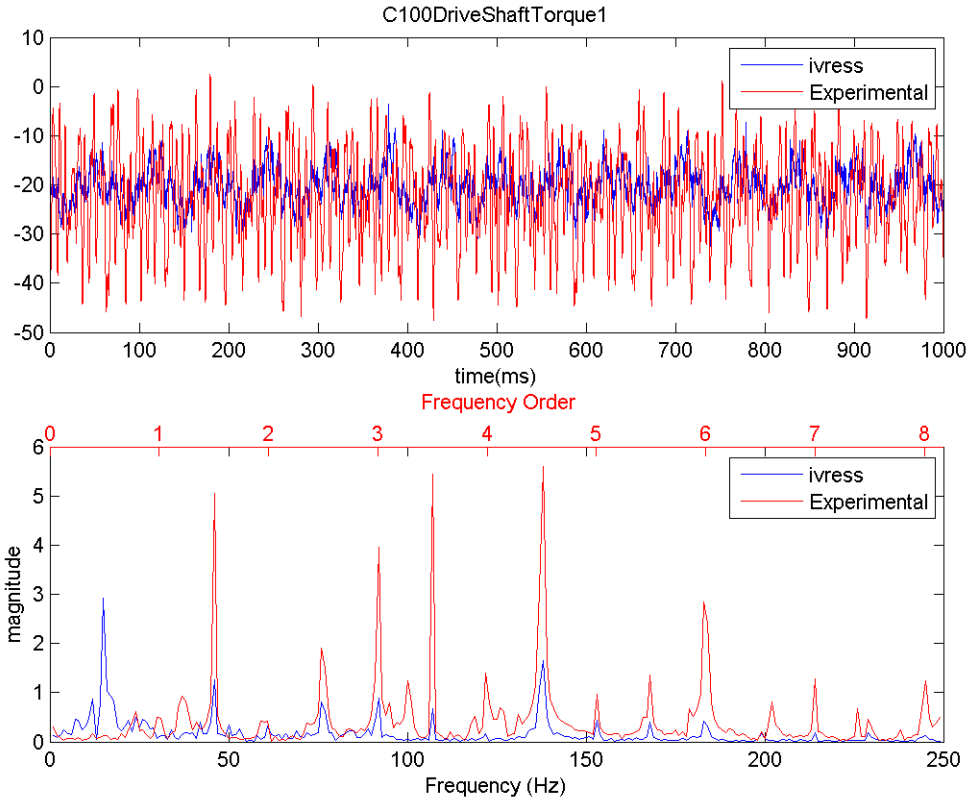

Figure 99 Drive shaft torque in the C100 operation range with bending stiffness increases to 2 $N.m^2$ instead of 0 $N.m^2$in the base line

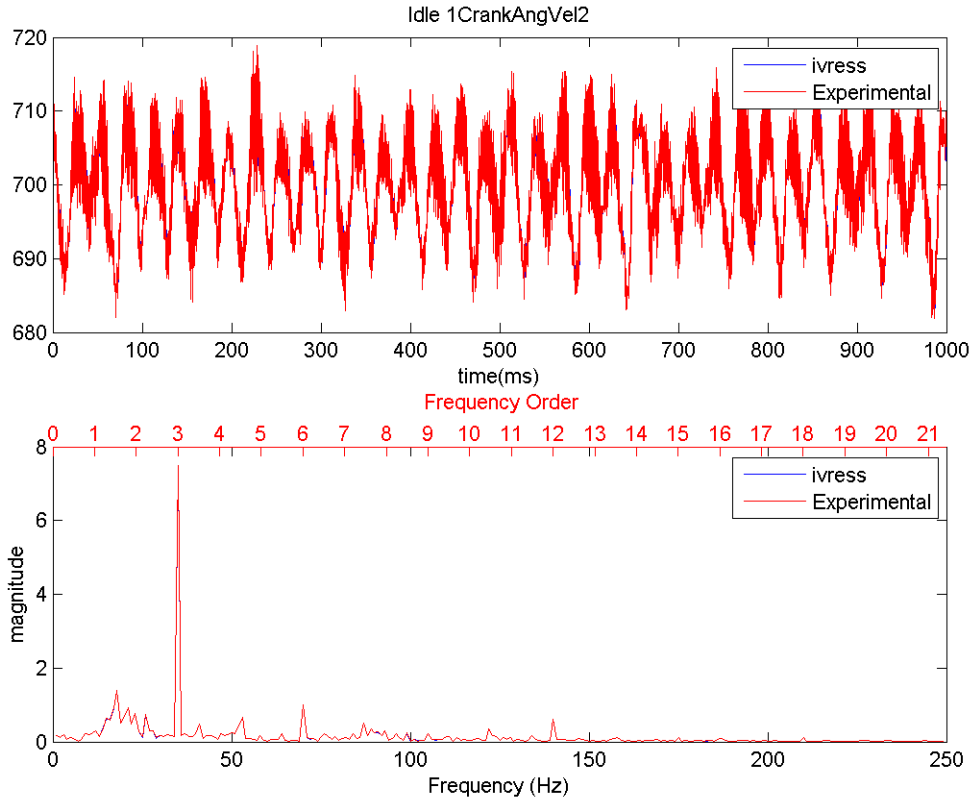

Figure 100 Crankshaft angular velocity in the idle operation range with belt bending stiffness increases to $2\ N.m^2$ instead of $0\ N.m^2$in the base line

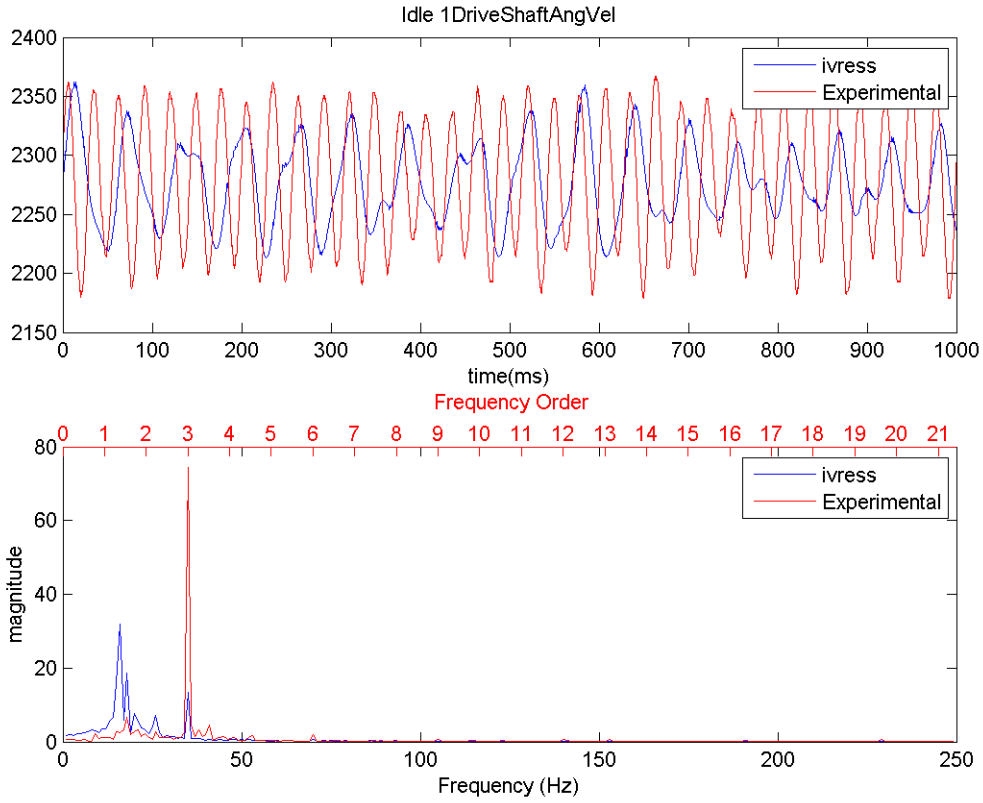

Figure 101 Drive shaft torque in the idle operation range with bending stiffness increases to 2 $N.m^2$ instead of 0 $N.m^2$in the base line

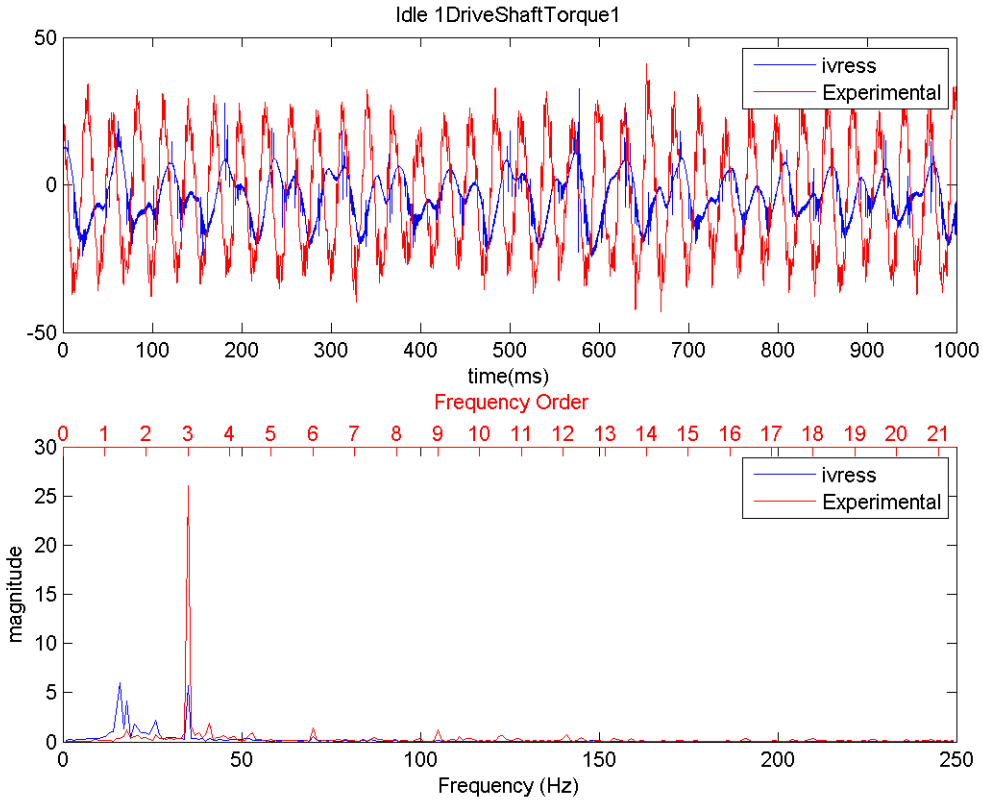

Figure 102 Drive shaft torque in the idle operation range with bending stiffness increases to 2 $N.m^2$ instead of 0 $N.m^2$in the base line

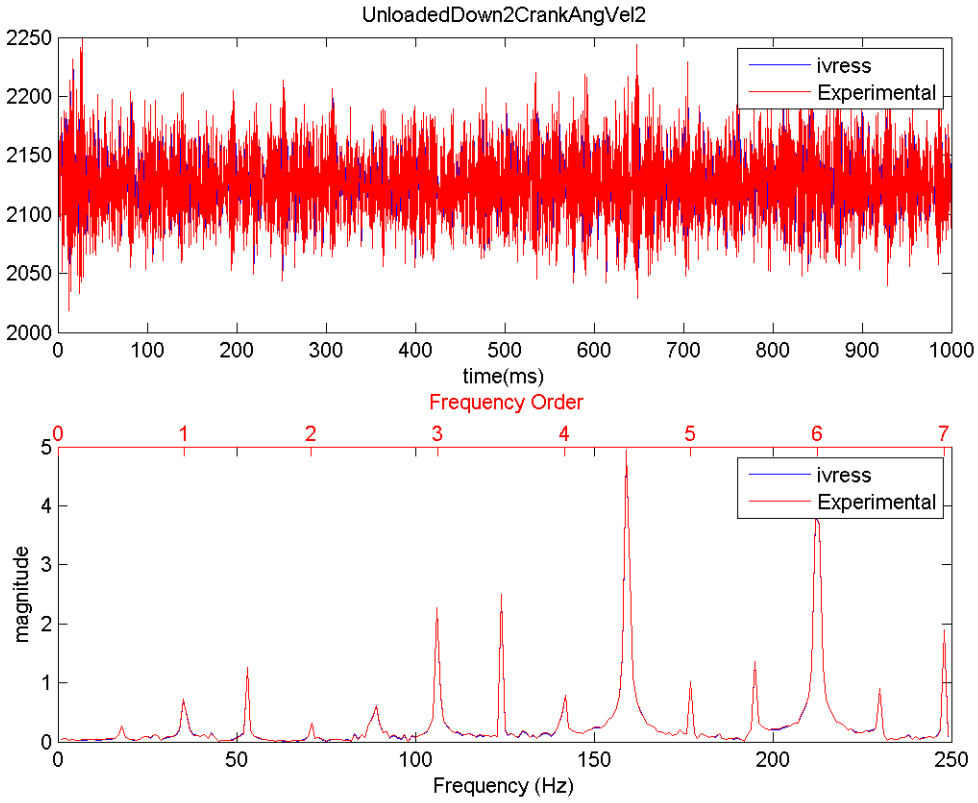

Figure 103 Crankshaft angular velocity in the UnloadedDown operation range with belt bending stiffness increases to 2 $N.m^2$ instead of 0 $N.m^2$in the base line

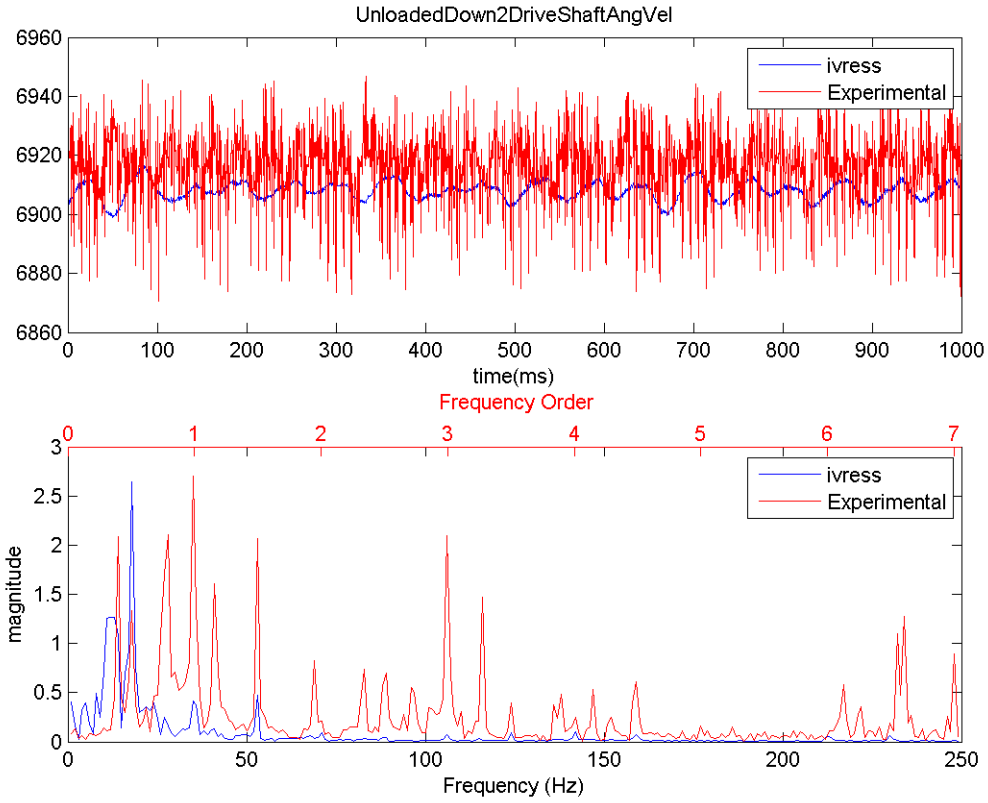

Figure 104 Drive shaft angular velocity in the UnloadedDown operation range with belt bending stiffness increases to 2 $N.m^2$ instead of 0 $N.m^2$in the base line

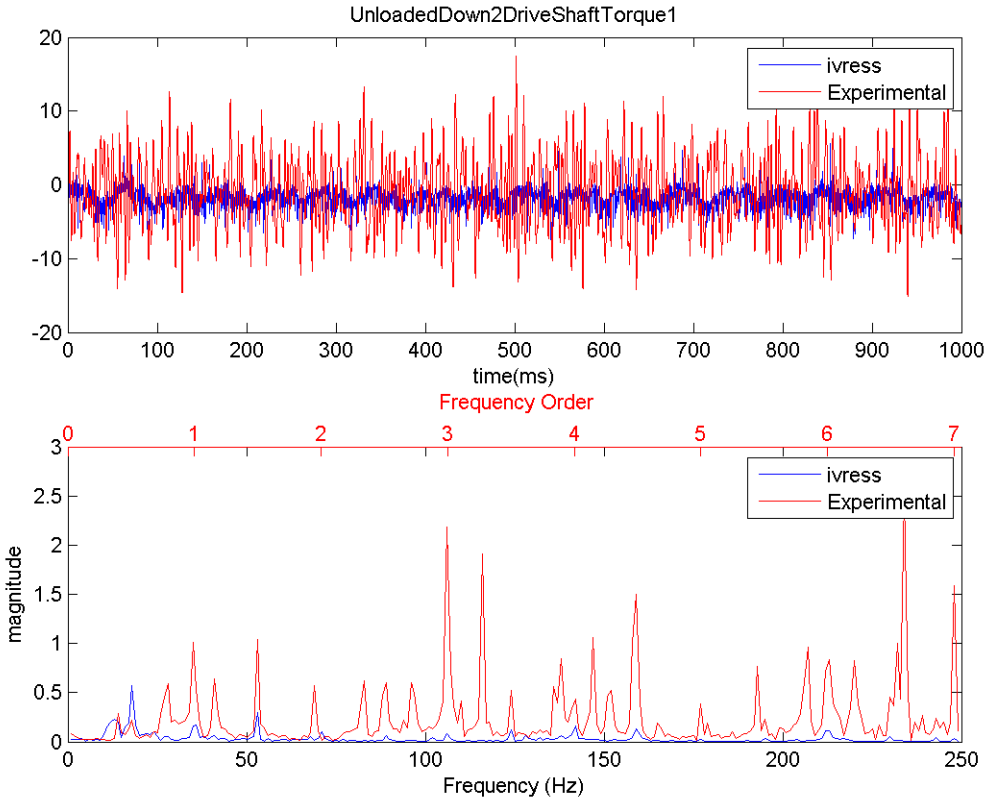

Figure 105 Drive shaft torque in the UnloadedDown operation range with bending stiffness increases to 2 $N.m^2$ instead of 0 $N.m^2$in the base line

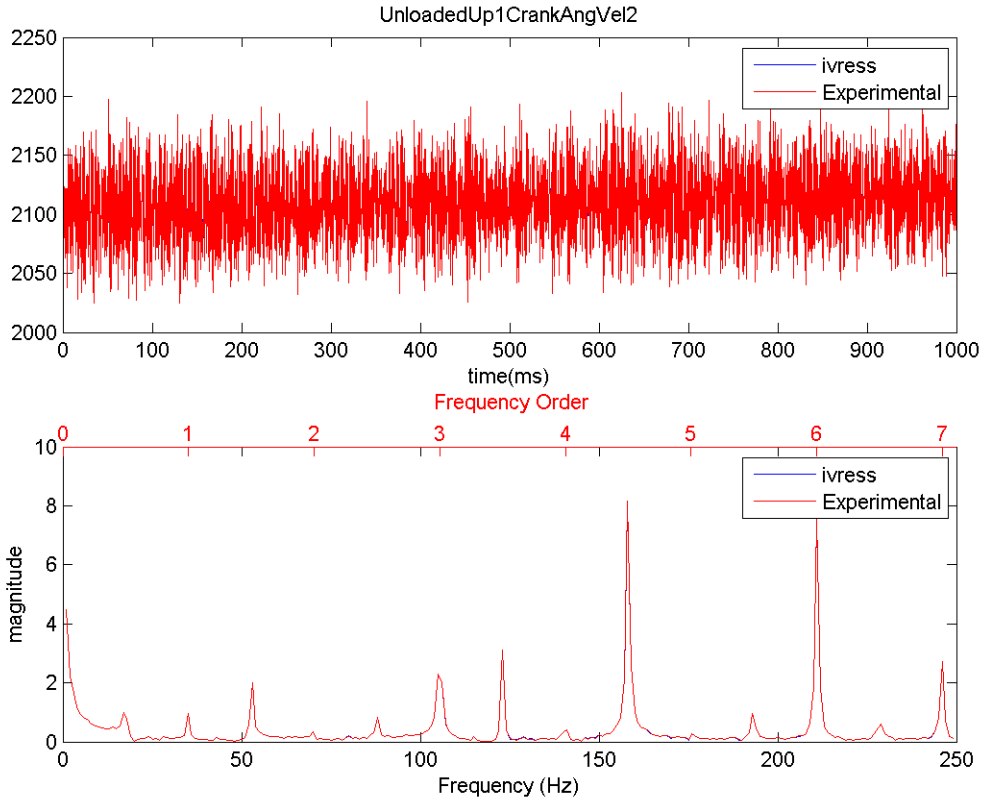

Figure 106 Crankshaft angular velocity in the UnloadedUp operation range with belt bending stiffness increases to 2 $N.m^2$ instead of 0 $N.m^2$in the base line

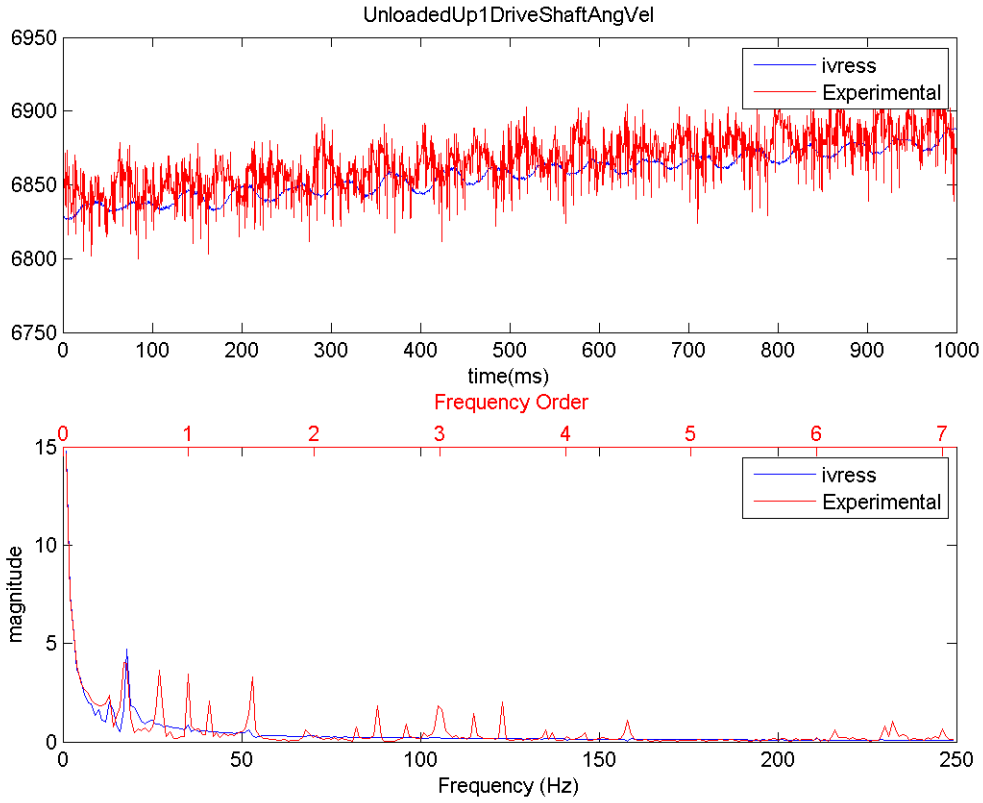

Figure 107 Drive shaft angular velocity in the UnloadedUp operation range with belt bending stiffness increases to 2 $N.m^2$ instead of 0 $N.m^2$in the base line

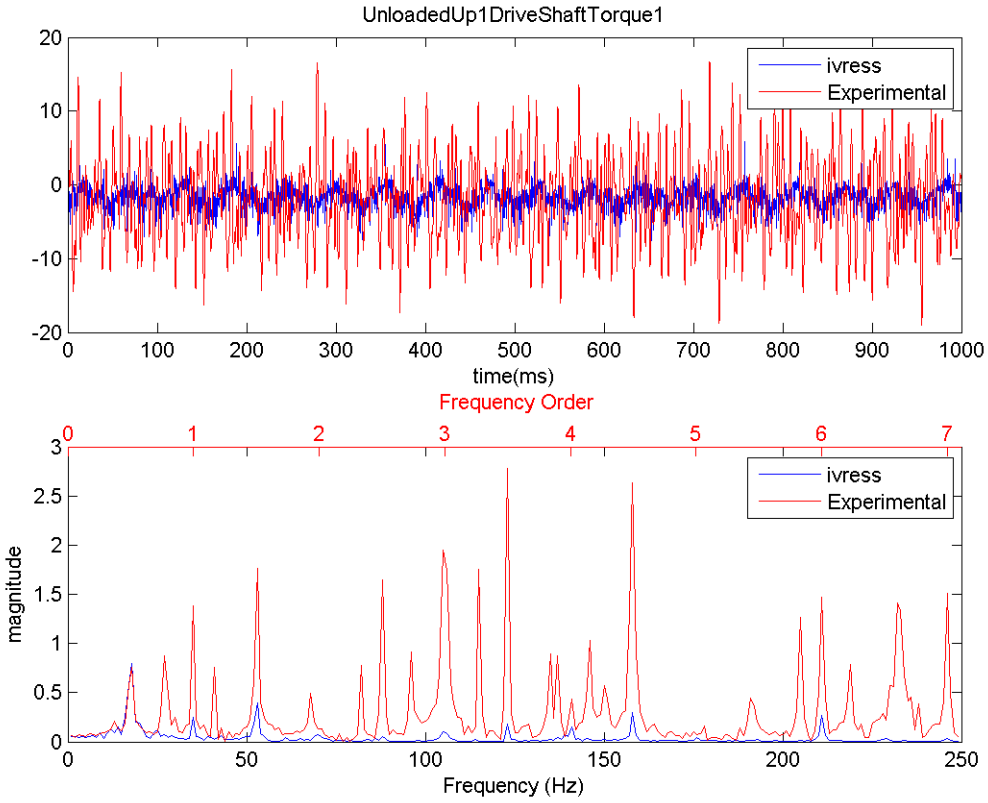

Figure 108 Drive shaft torque in the UnloadedUp operation range with bending stiffness increases to 2 $N.m^2$ instead of 0 $N.m^2$in the base line

7 Belt Coefficient Of Friction Increased to 1 Instead of 0.6 in the Baseline

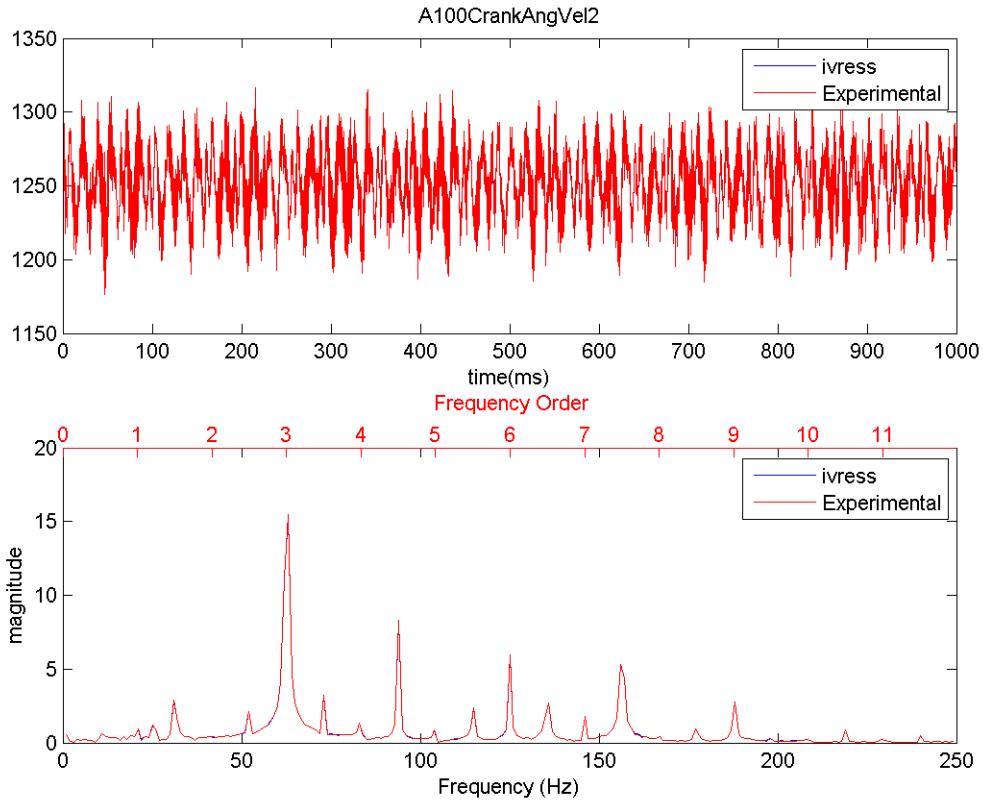

Figure 109 Crankshaft angular velocity in the A100 operation range with belt coefficient of friction increased to 1 instead of 0.6 in the baseline

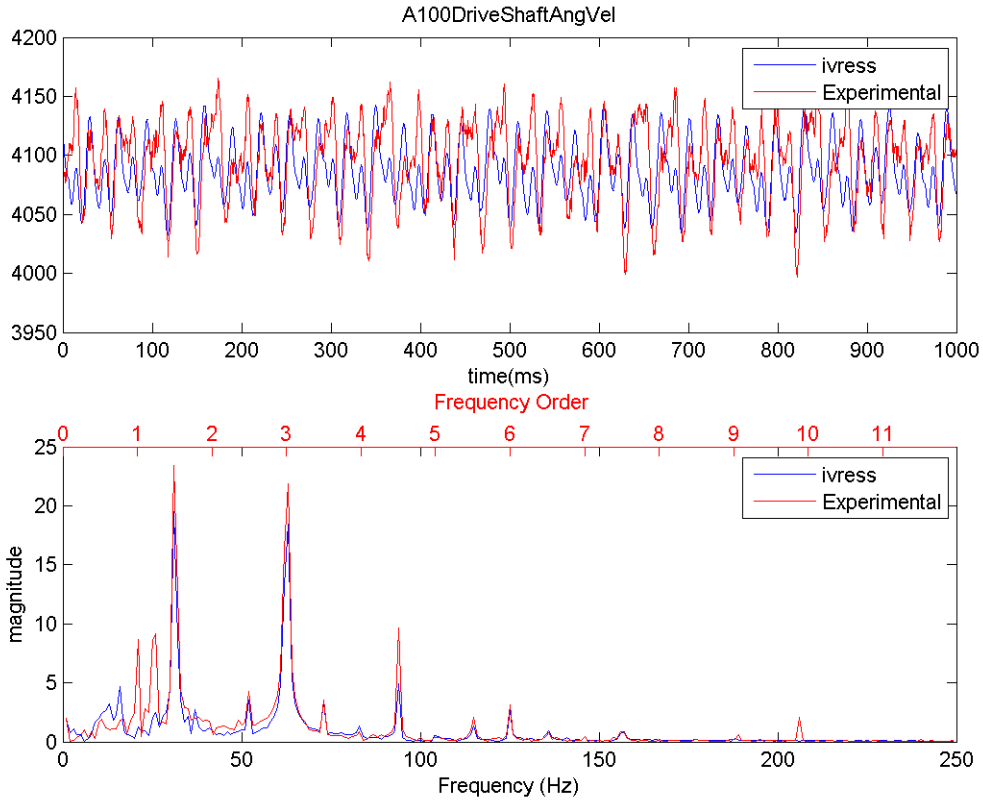

Figure 110 Drive shaft angular velocity in the A100 operation range with belt coefficient of friction increased to 1 instead of 0.6 in the baseline

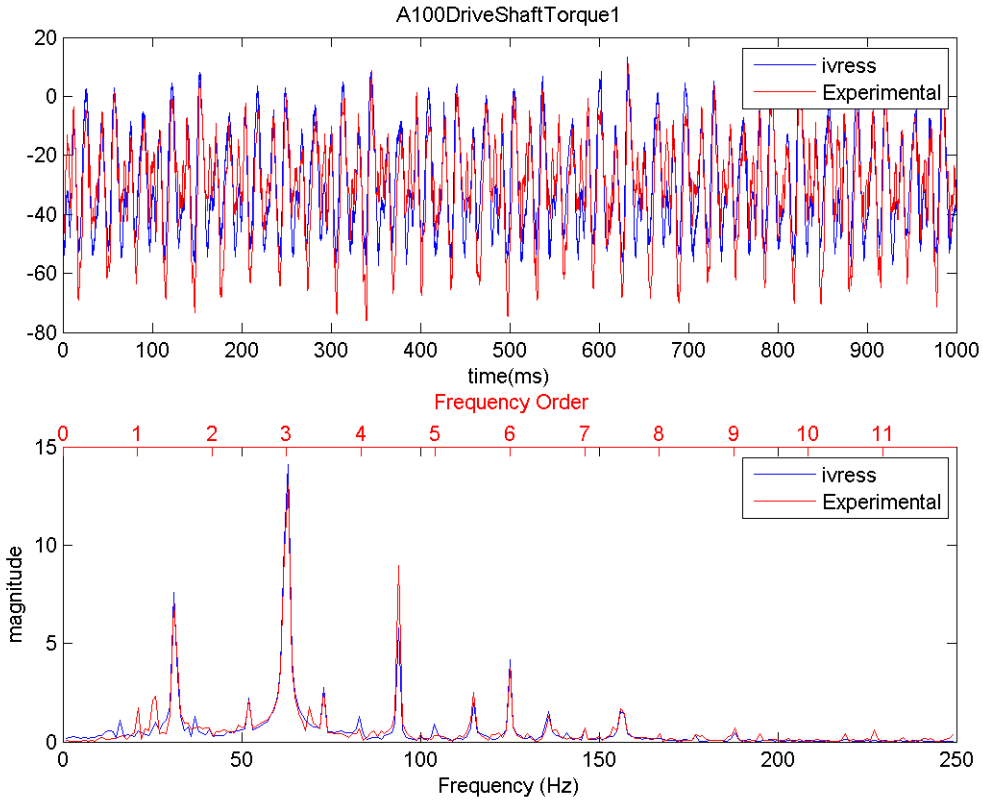

Figure 111 Drive shaft torque in the A100 operation range with belt coefficient of friction increased to 1 instead of 0.6 in the baseline

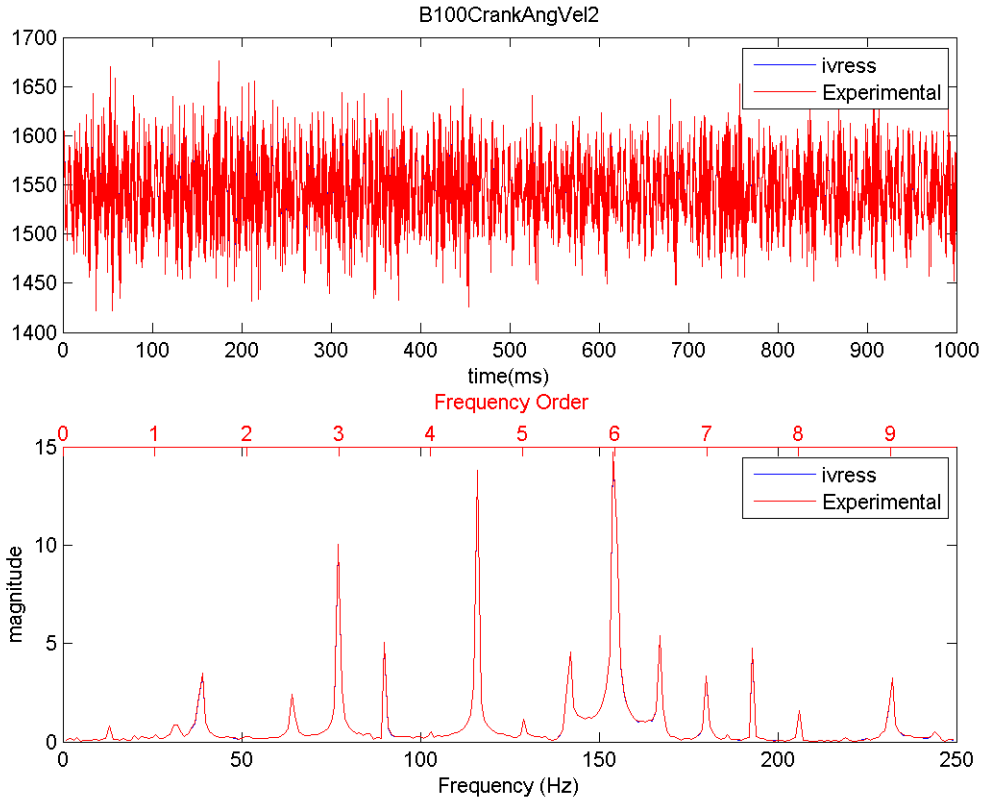

Figure 112 Crankshaft angular velocity in the B100 operation range with belt coefficient of friction increased to 1 instead of 0.6 in the baseline

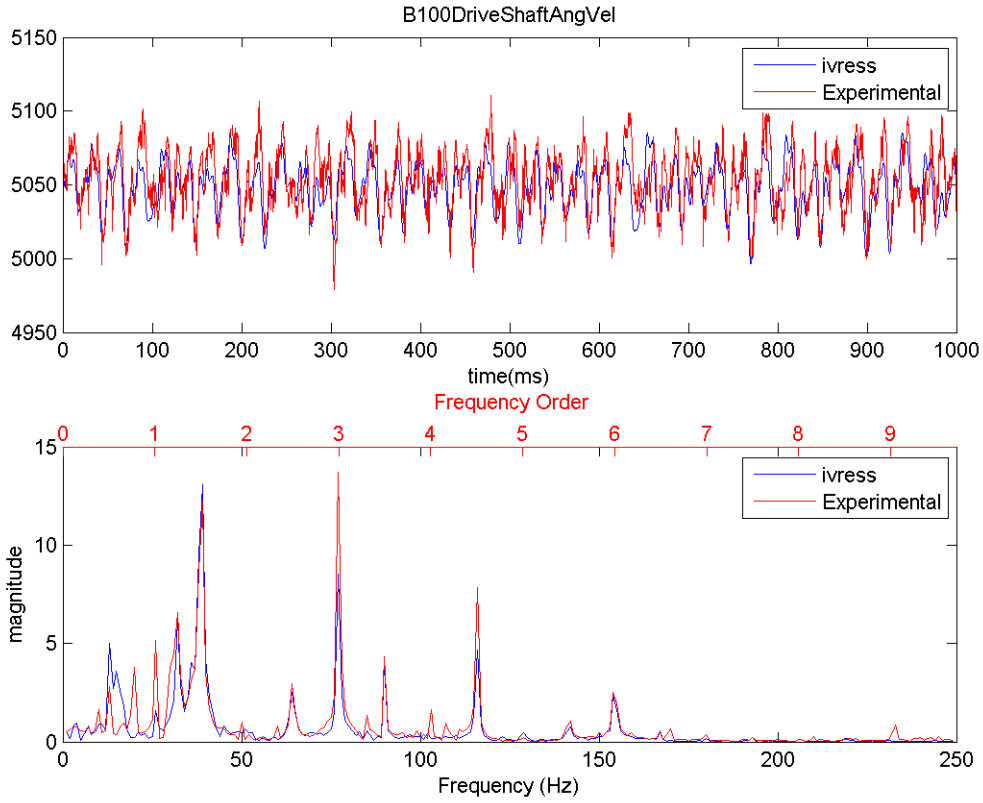

Figure 113 Drive shaft angular velocity in the B100 operation range with belt coefficient of friction increased to 1 instead of 0.6 in the baseline

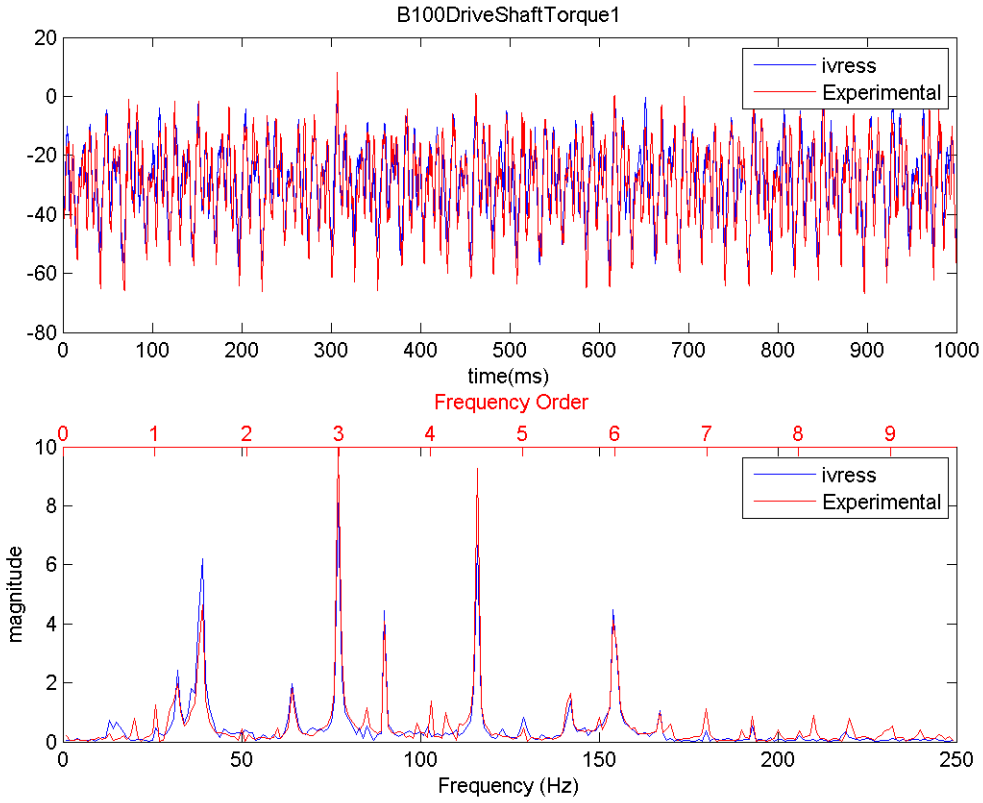

Figure 114 Drive shaft torque in the B100 operation range with belt coefficient of friction increased to 1 instead of 0.6 in the baseline

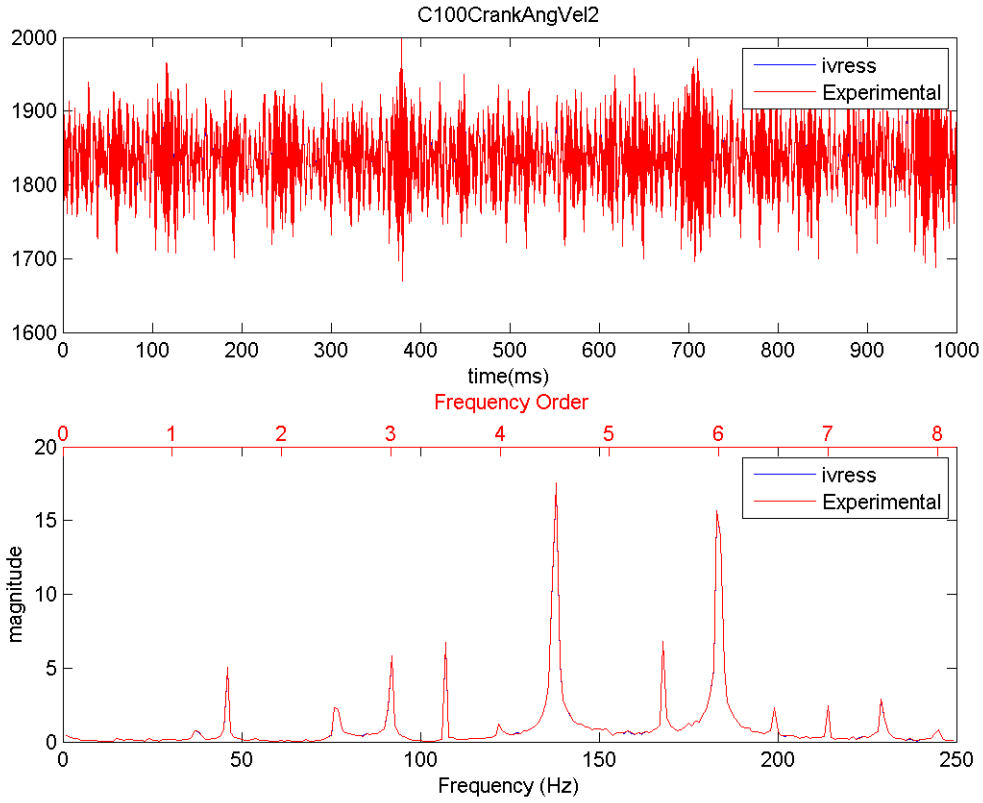

Figure 115 Crankshaft angular velocity in the C100 operation range with belt coefficient of friction increased to 1 instead of 0.6 in the baseline

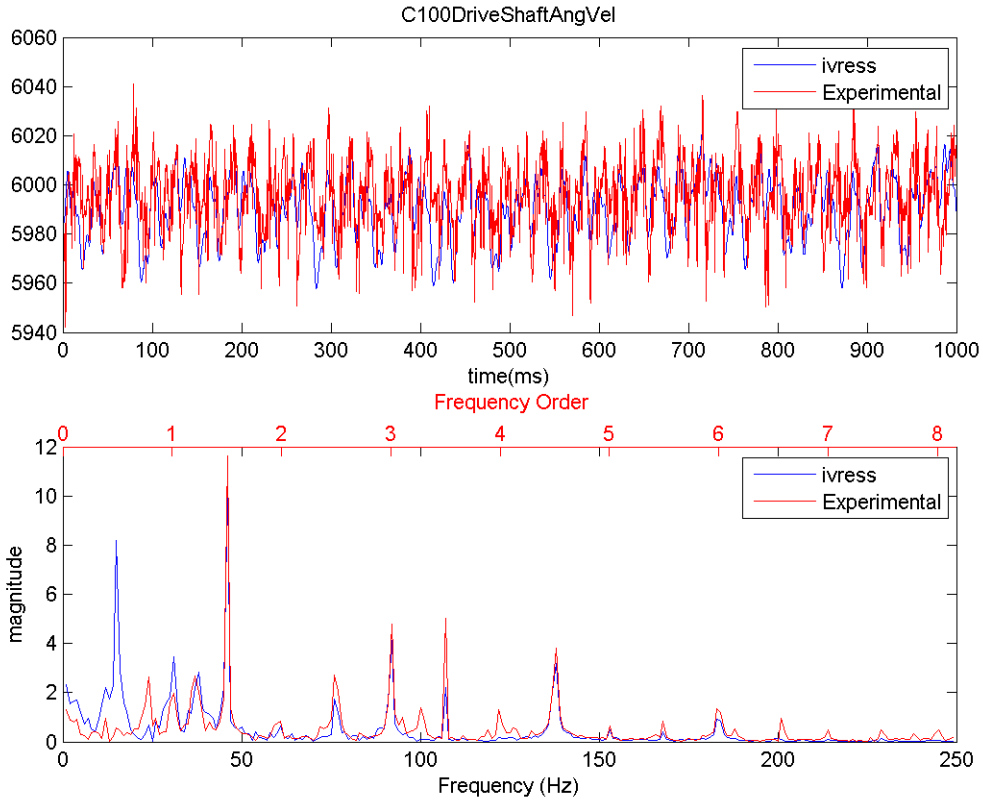

Figure 116 Drive shaft angular velocity in the C100 operation range with belt coefficient of friction increased to 1 instead of 0.6 in the baseline

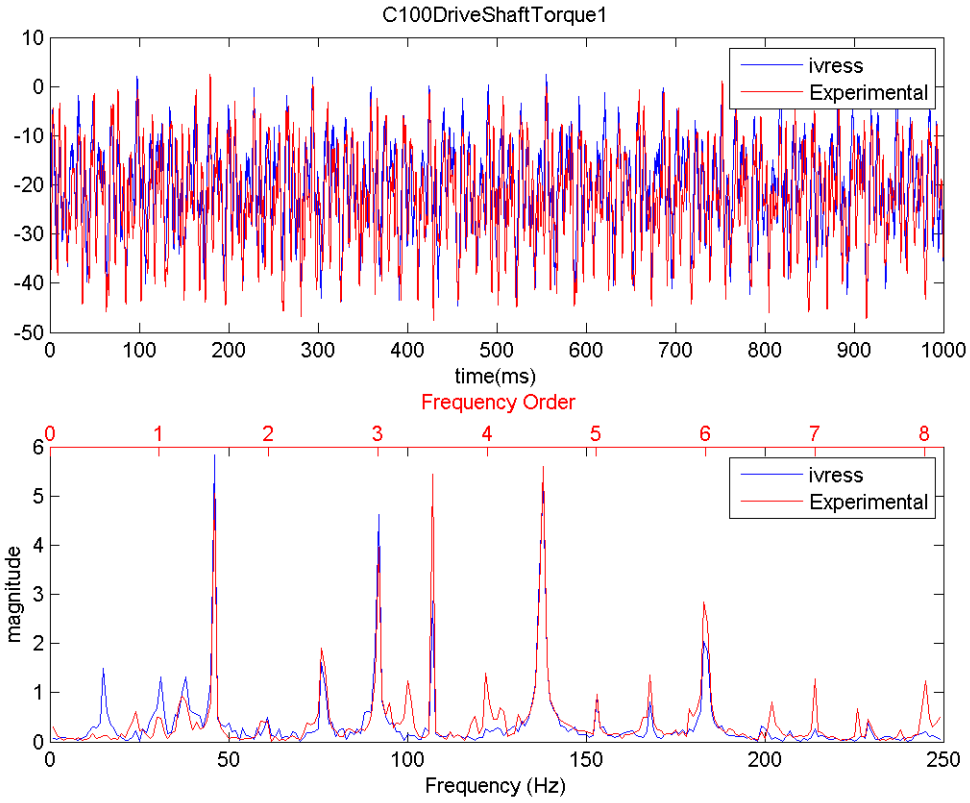

Figure 117 Drive shaft torque in the C100 operation range with belt coefficient of friction increased to 1 instead of 0.6 in the baseline

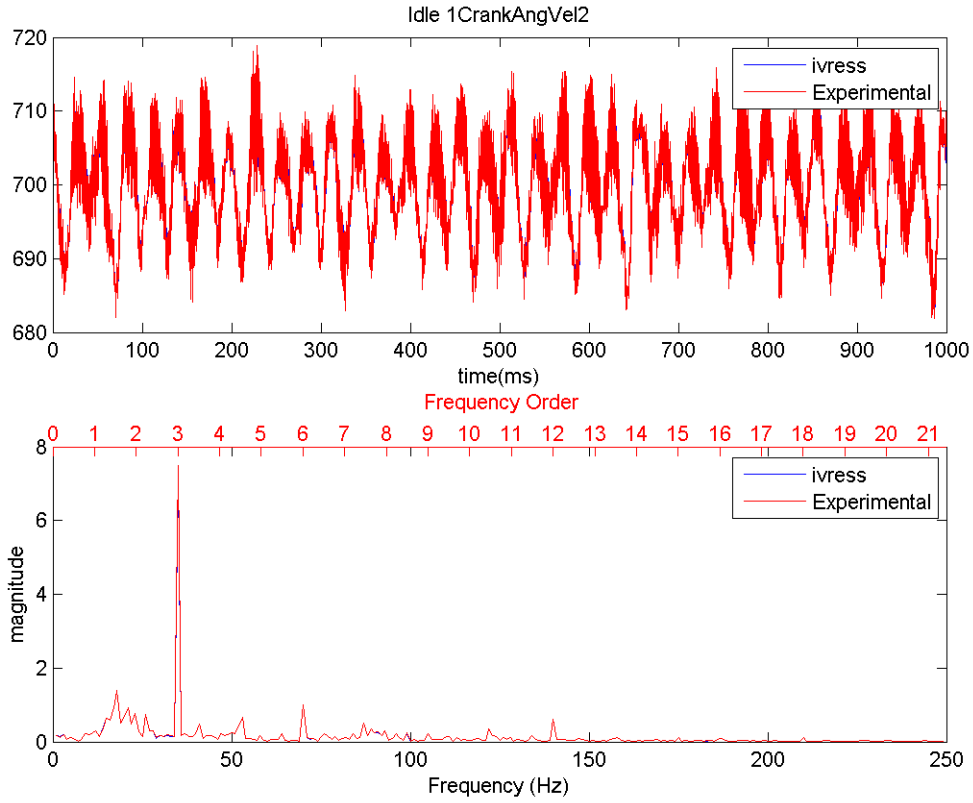

Figure 118 Crankshaft angular velocity in the idle operation range with belt coefficient of friction increased to 1 instead of 0.6 in the baseline

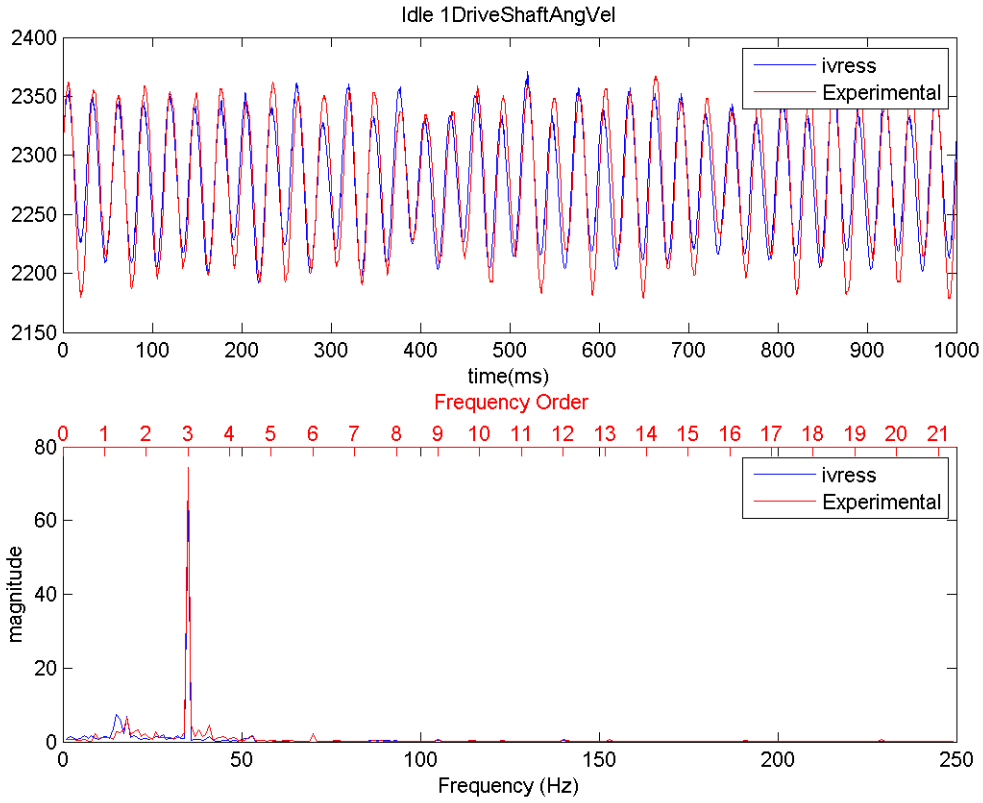

Figure 119 Drive shaft angular velocity in the idle operation range with belt coefficient of friction increased to 1 instead of 0.6 in the baseline

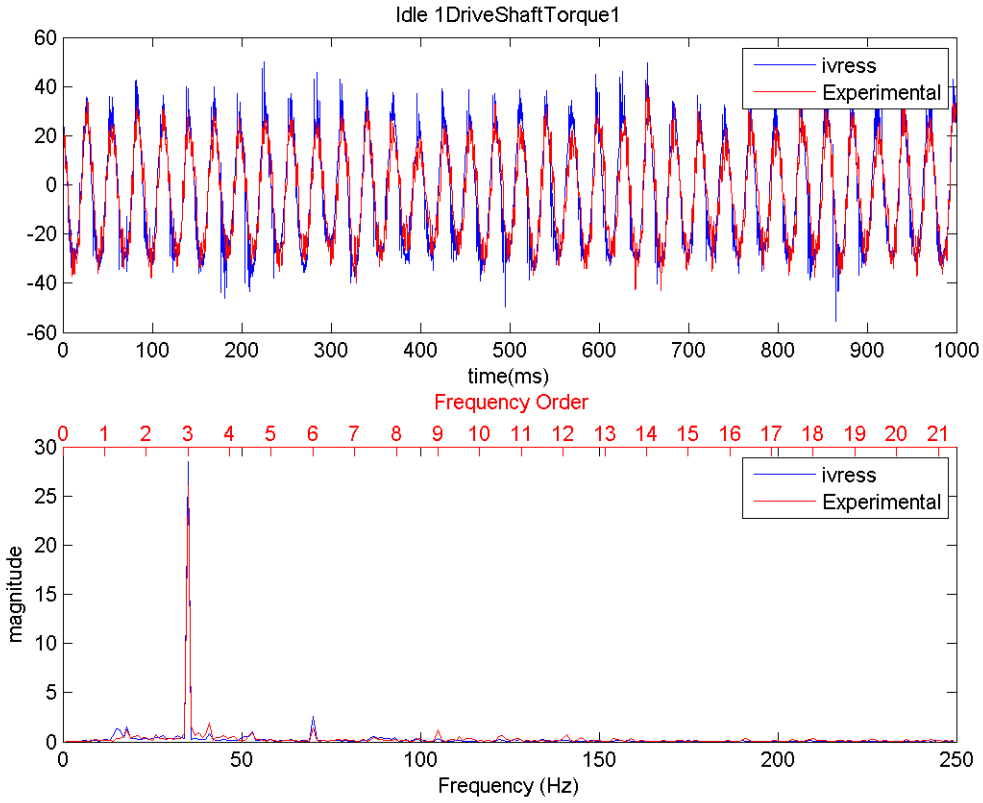

Figure 120 Drive shaft torque in the idle operation range with belt coefficient of friction increased to 1 instead of 0.6 in the baseline

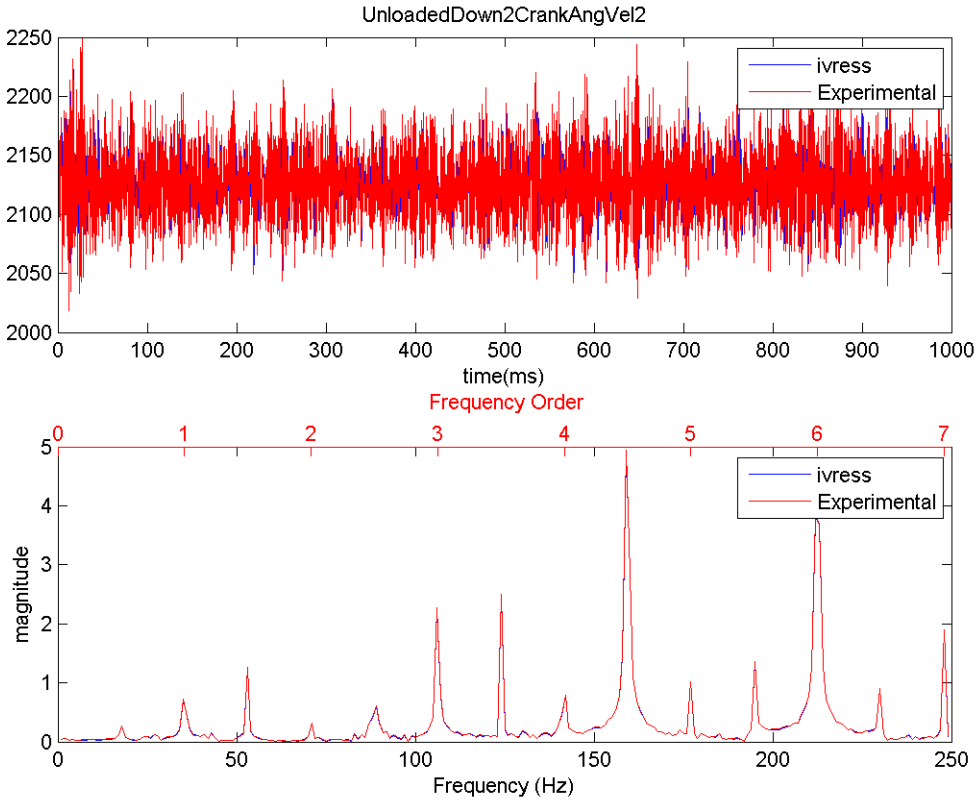

Figure 121 Crankshaft angular velocity in the UnloadedDown operation range with belt coefficient of friction increased to 1 instead of 0.6 in the baseline

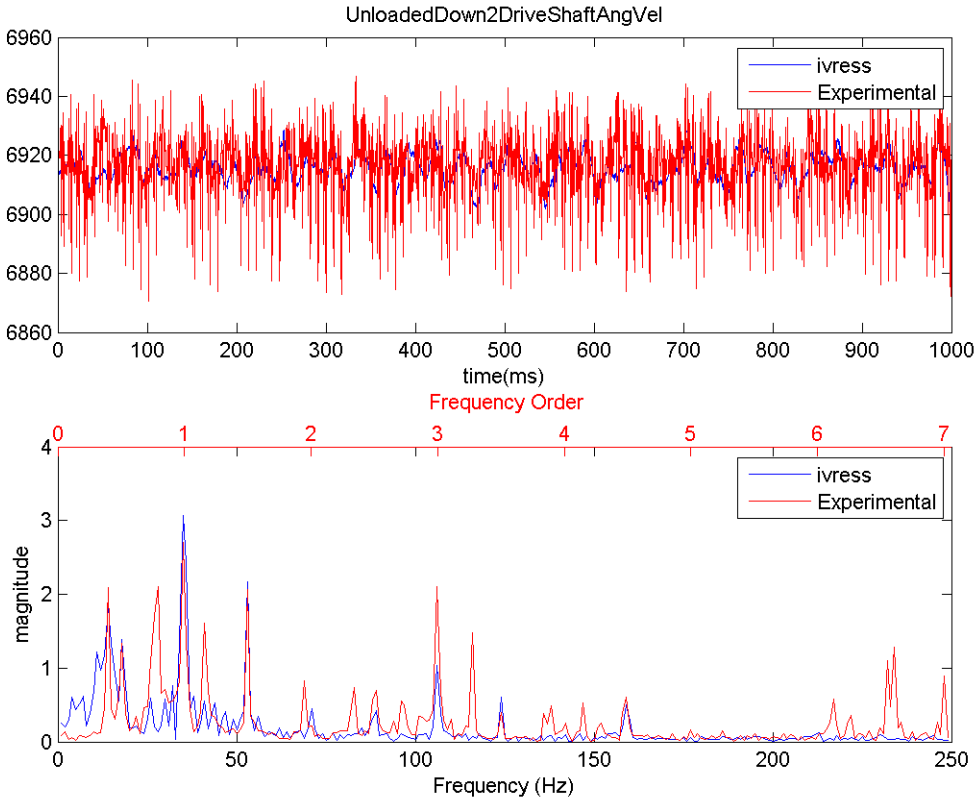

Figure 122 Drive shaft angular velocity in the UnloadedDown operation range with belt coefficient of friction increased to 1 instead of 0.6 in the baseline

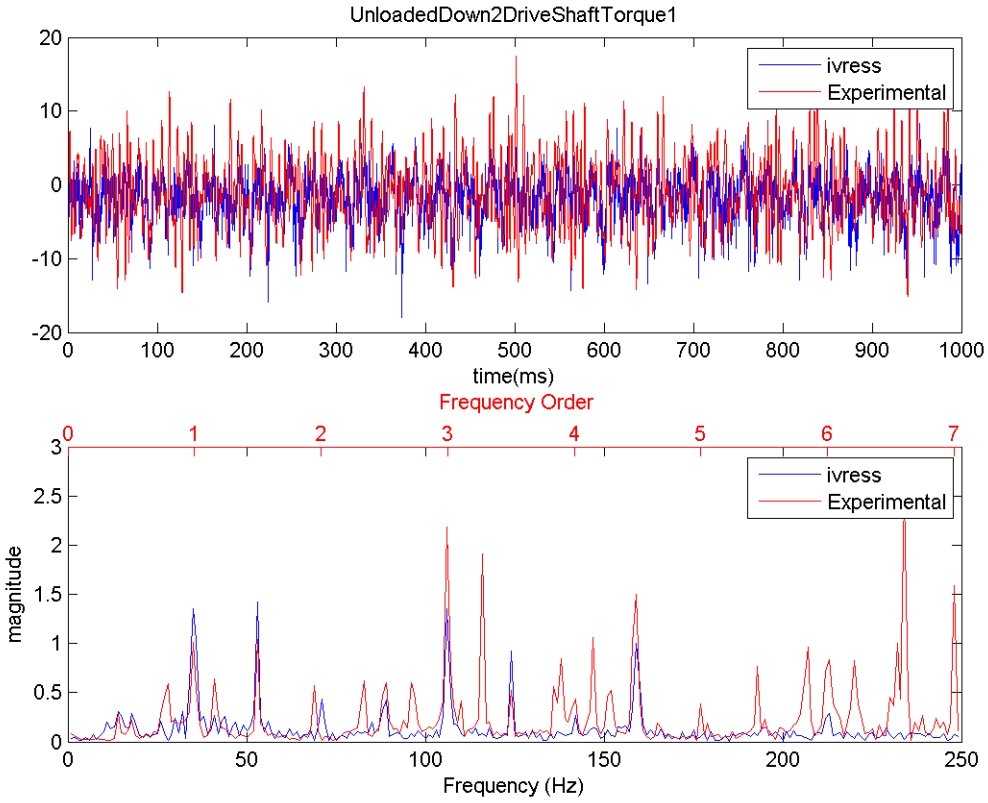

Figure 123 Drive shaft torque in the UnloadedDown operation range with belt coefficient of friction increased to 1 instead of 0.6 in the baseline

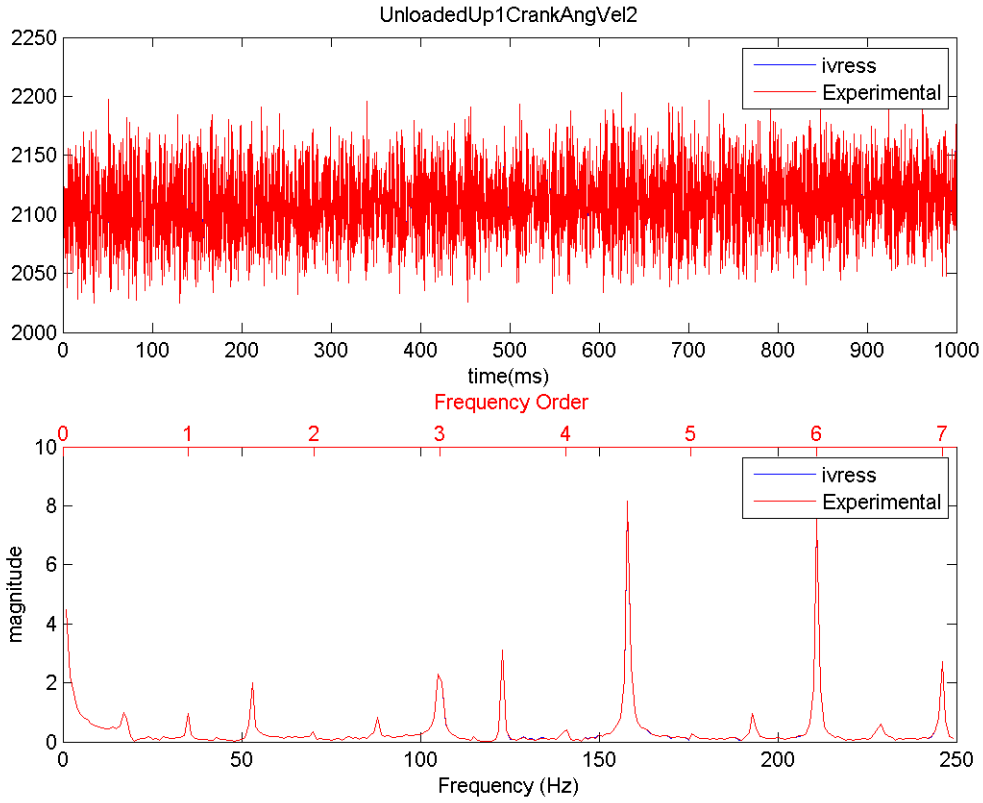

Figure 124 Crankshaft angular velocity in the UnloadedUp operation range with belt coefficient of friction increased to 1 instead of 0.6 in the baseline

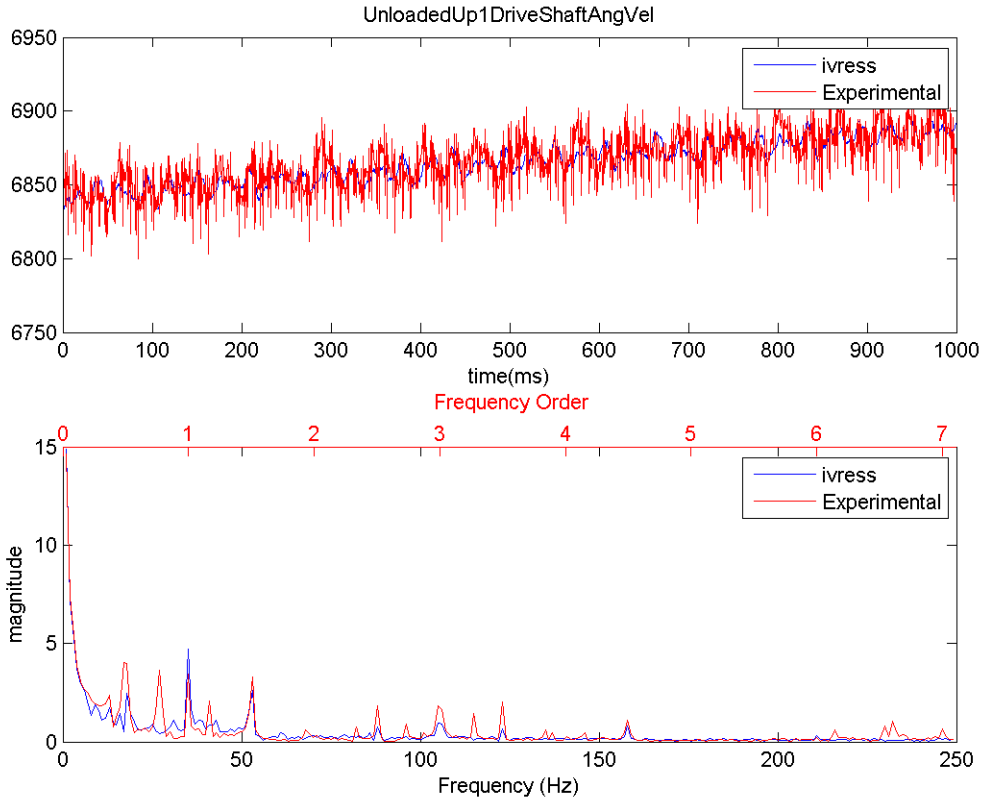

Figure 125 Drive shaft angular velocity in the UnloadedUp operation range with belt coefficient of friction increased to 1 instead of 0.6 in the baseline

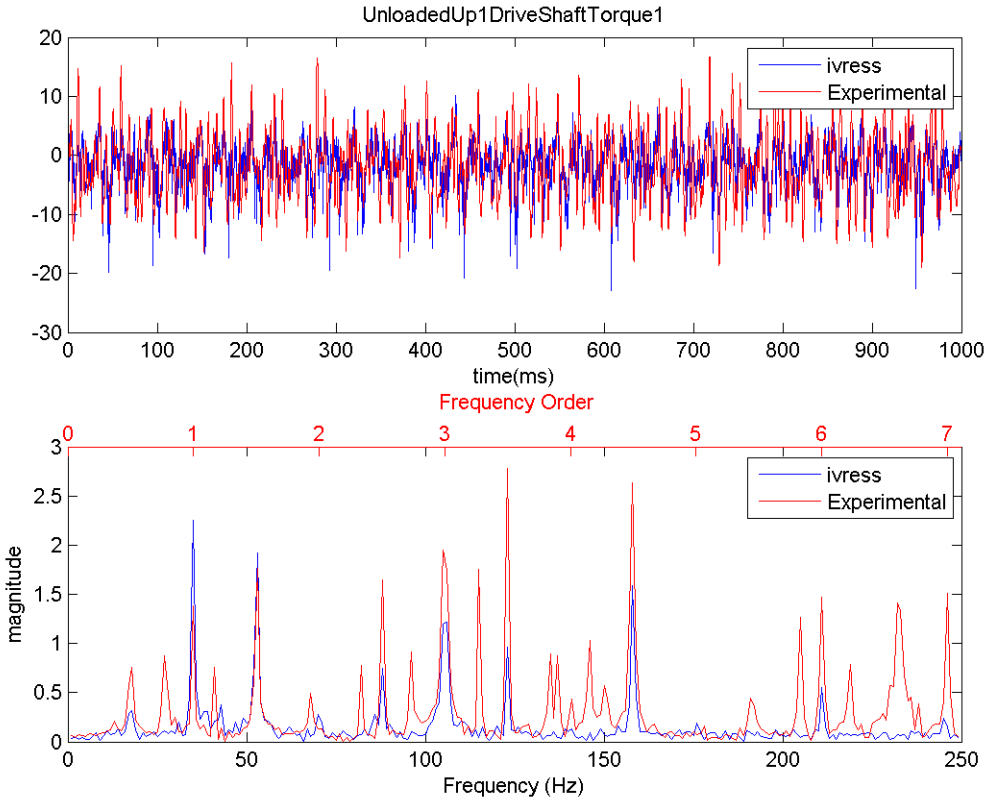

Figure 126 Drive shaft torque in the UnloadedUp operation range with belt coefficient of friction increased to 1 instead of 0.6 in the baseline

8 Belt Coefficient of Friction Decreased to 0.4 Instead of 0.6 in the Baseline

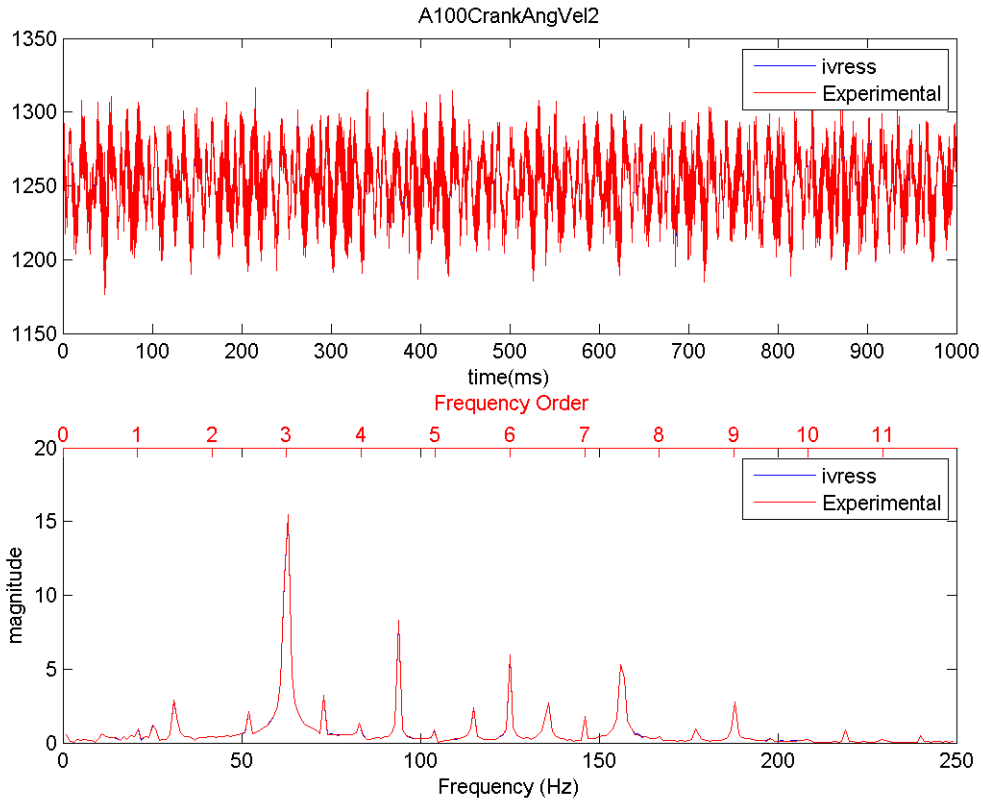

Figure 127 Crankshaft angular velocity in the A100 operation range with belt coefficient of friction decreased to 0.4 instead of 0.6 in the baseline

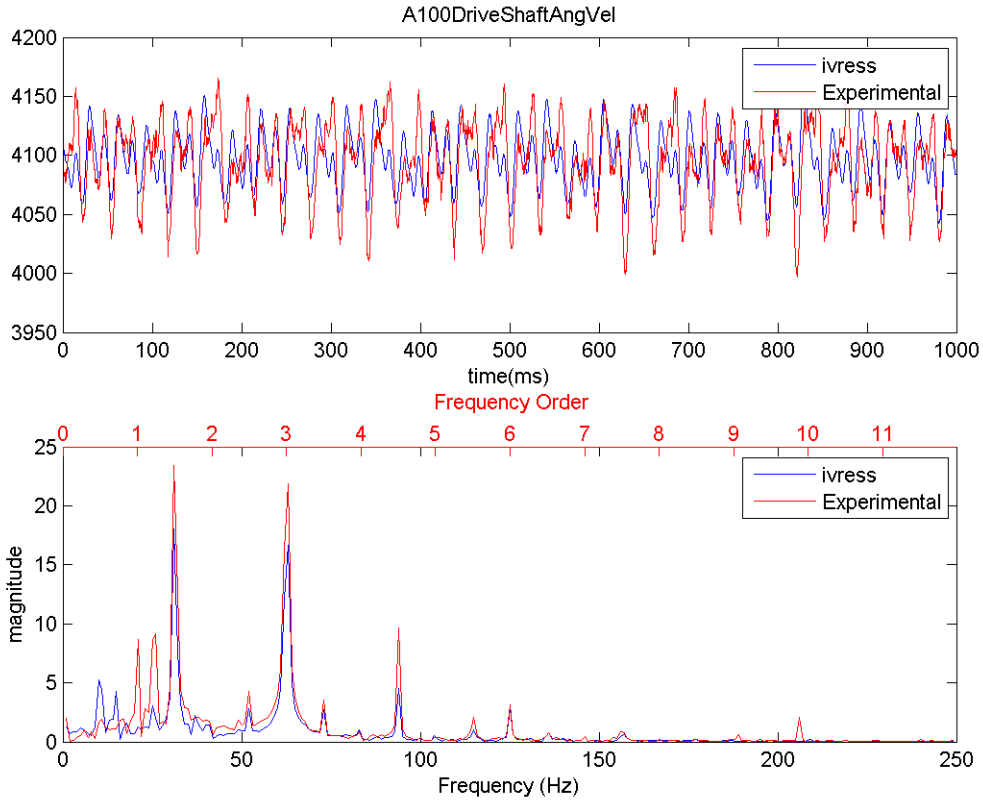

Figure 128 Drive shaft angular velocity in the A100 operation range with belt coefficient of friction decreased to 0.4 instead of 0.6 in the baseline

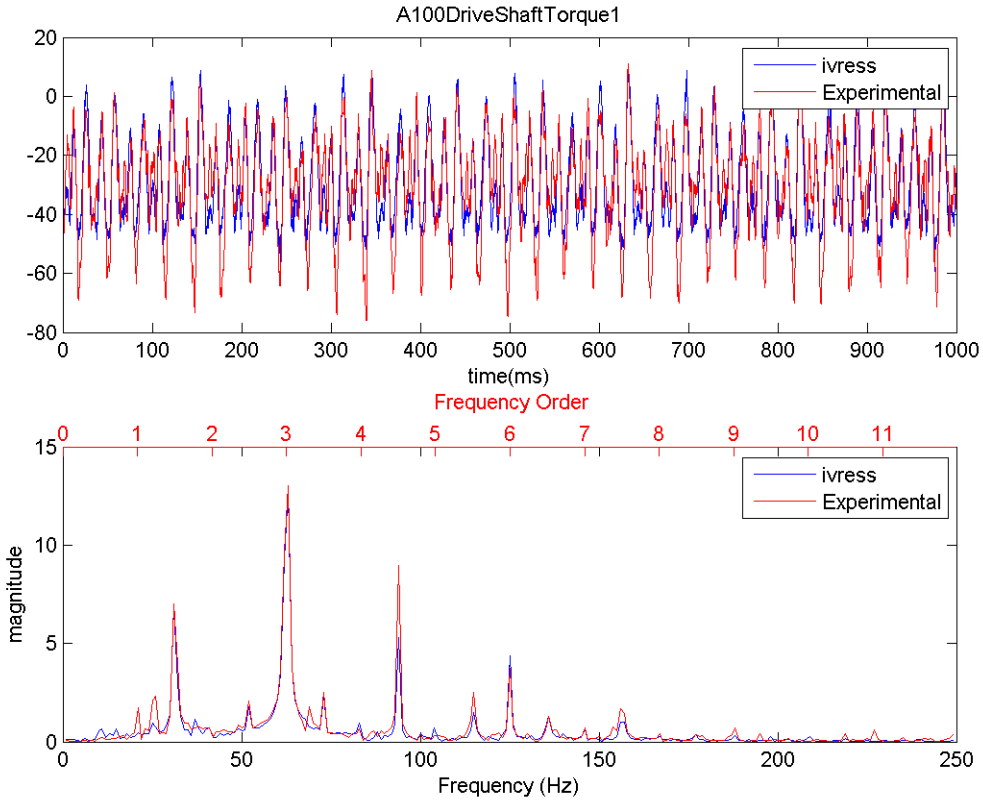

Figure 129 Drive shaft torque in the A100 operation range with belt coefficient of friction decreased to 0.4 instead of 0.6 in the baseline

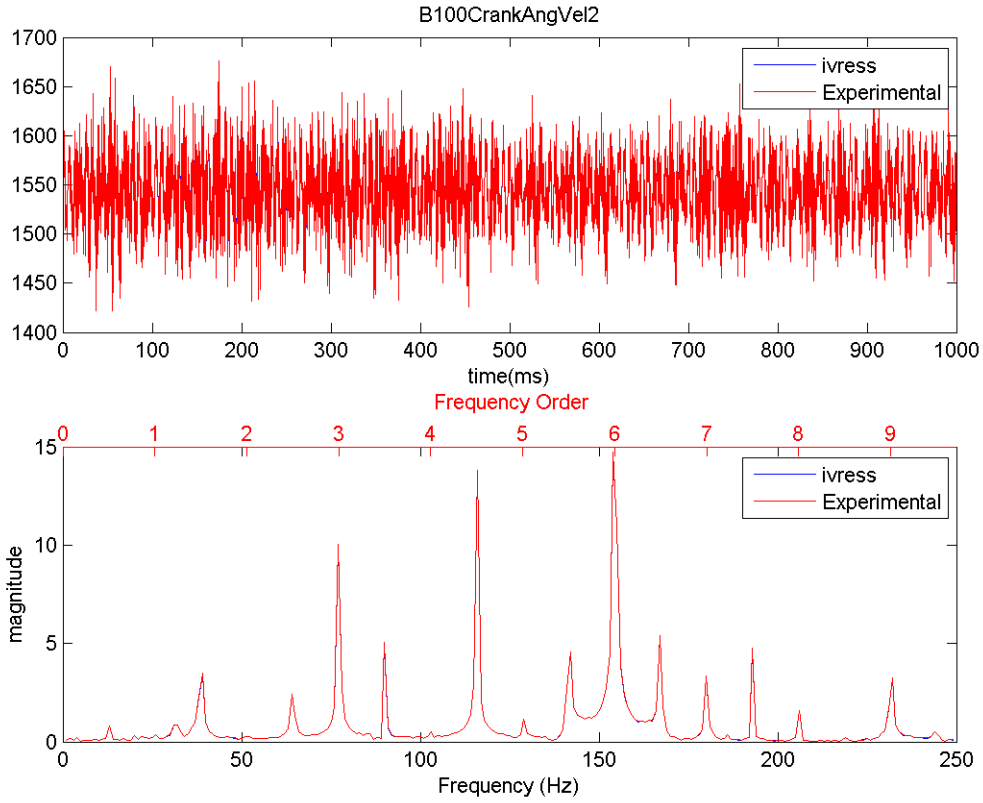

Figure 130 Crankshaft angular velocity in the B100 operation range with belt coefficient of friction decreased to 0.4 instead of 0.6 in the baseline

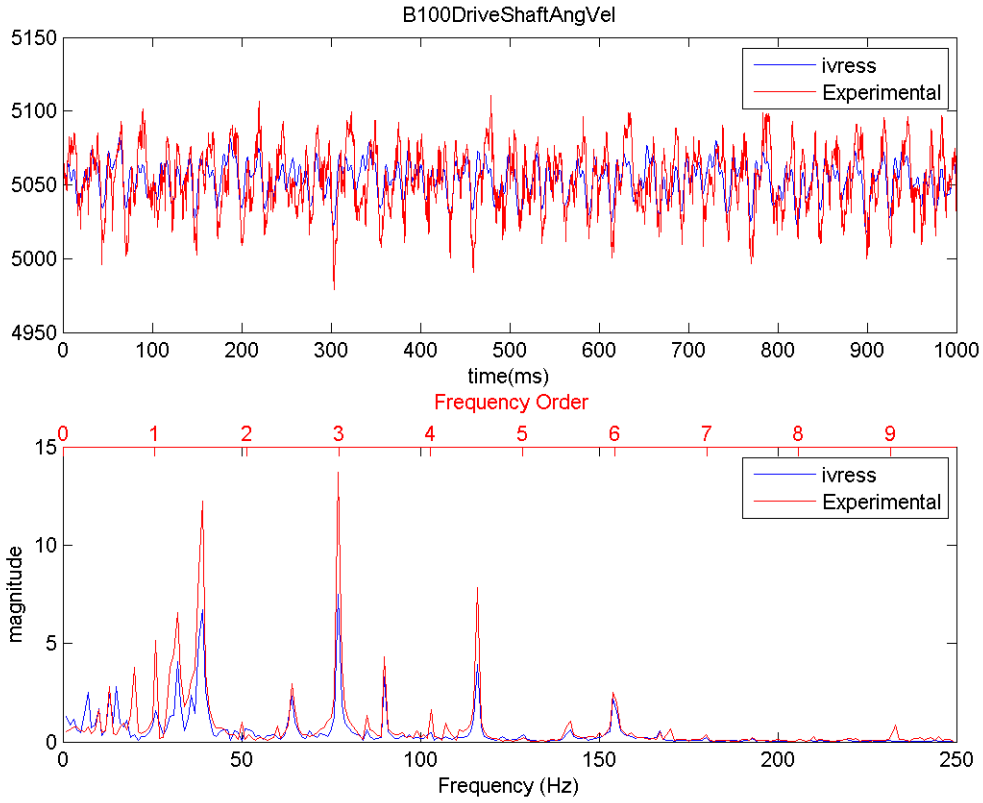

Figure 131 Drive shaft angular velocity in the B100 operation range with belt coefficient of friction decreased to 0.4 instead of 0.6 in the baseline

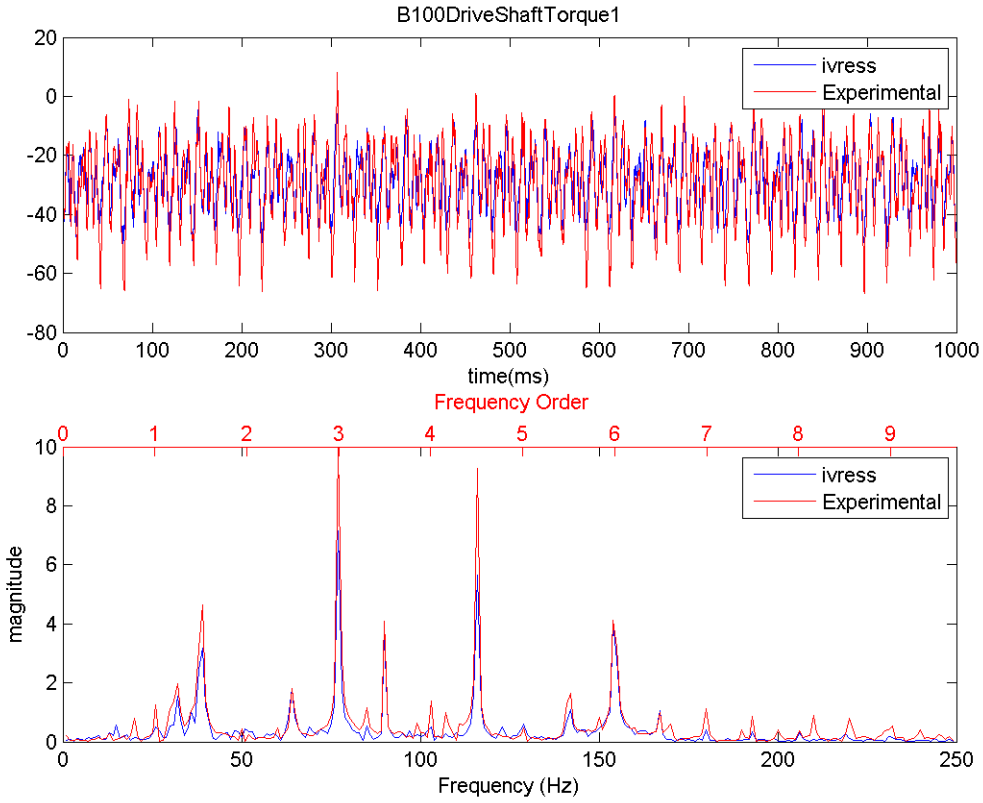

Figure 132 Drive shaft torque in the B100 operation range with belt coefficient of friction decreased to 0.4 instead of 0.6 in the baseline

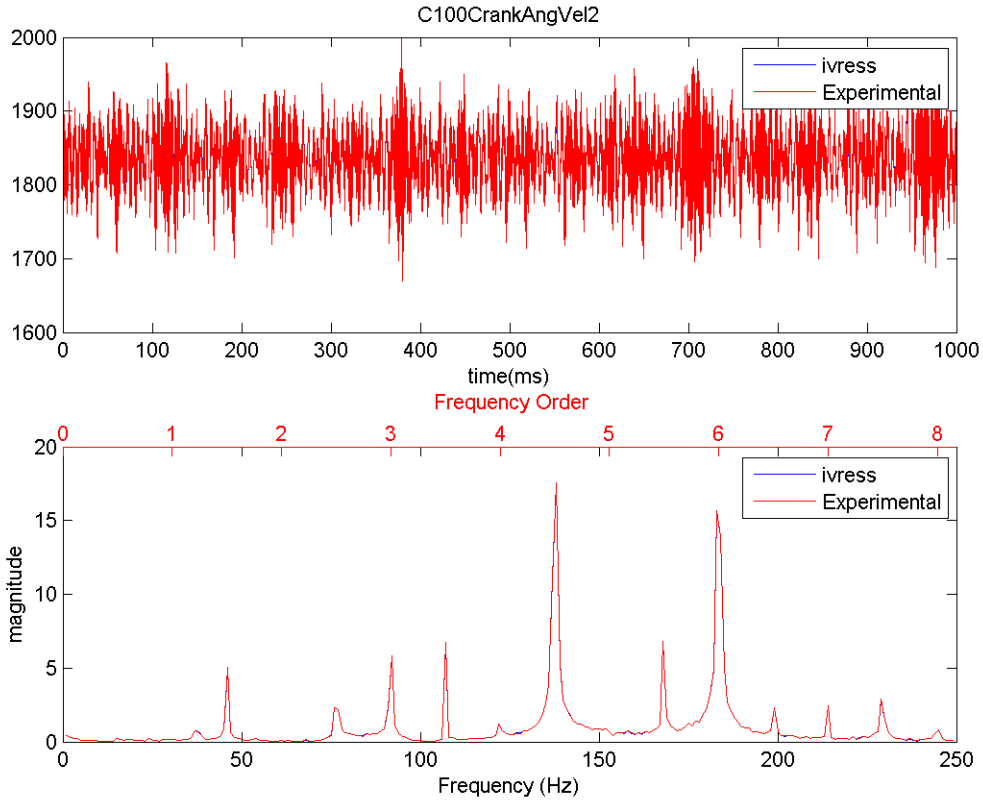

Figure 133 Crankshaft angular velocity in the C100 operation range with belt coefficient of friction decreased to 0.4 instead of 0.6 in the baseline

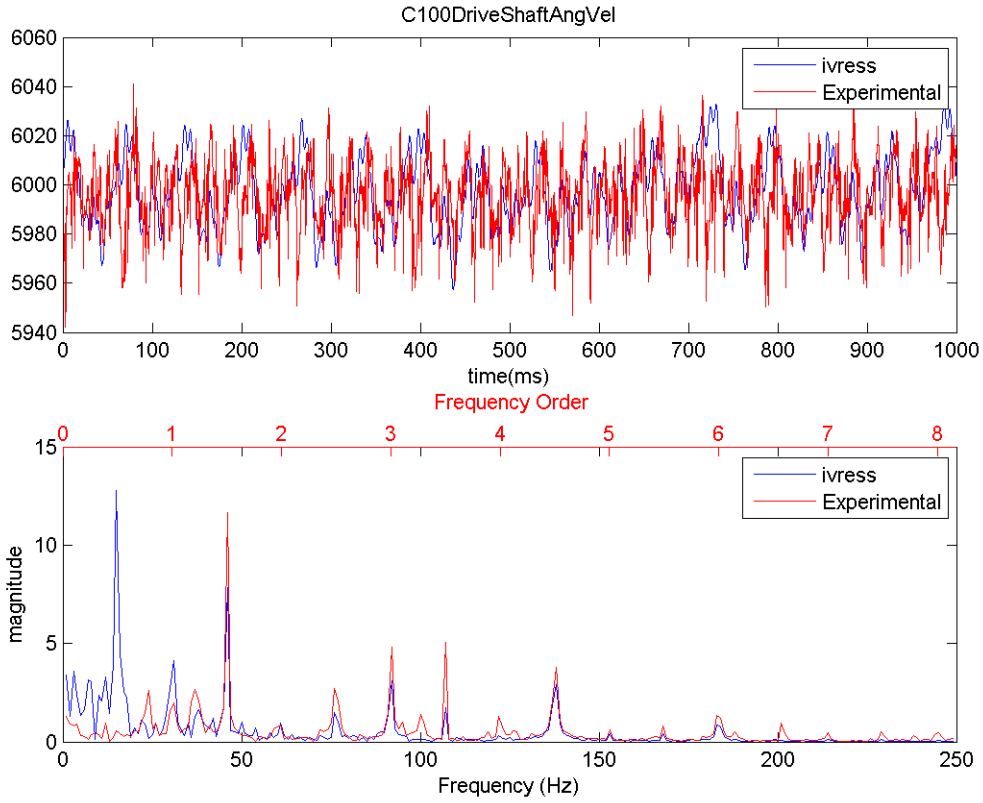

Figure 134 Drive shaft angular velocity in the C100 operation range with belt coefficient of friction decreased to 0.4 instead of 0.6 in the baseline

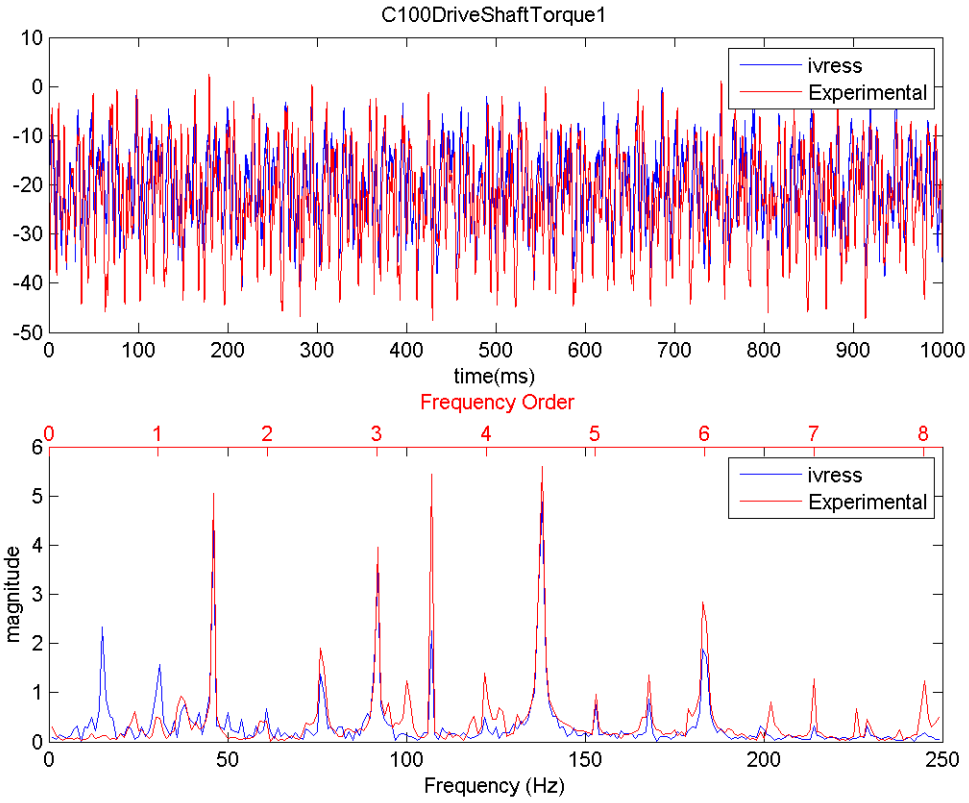

Figure 135 Drive shaft torque in the C100 operation range with belt coefficient of friction decreased to 0.4 instead of 0.6 in the baseline

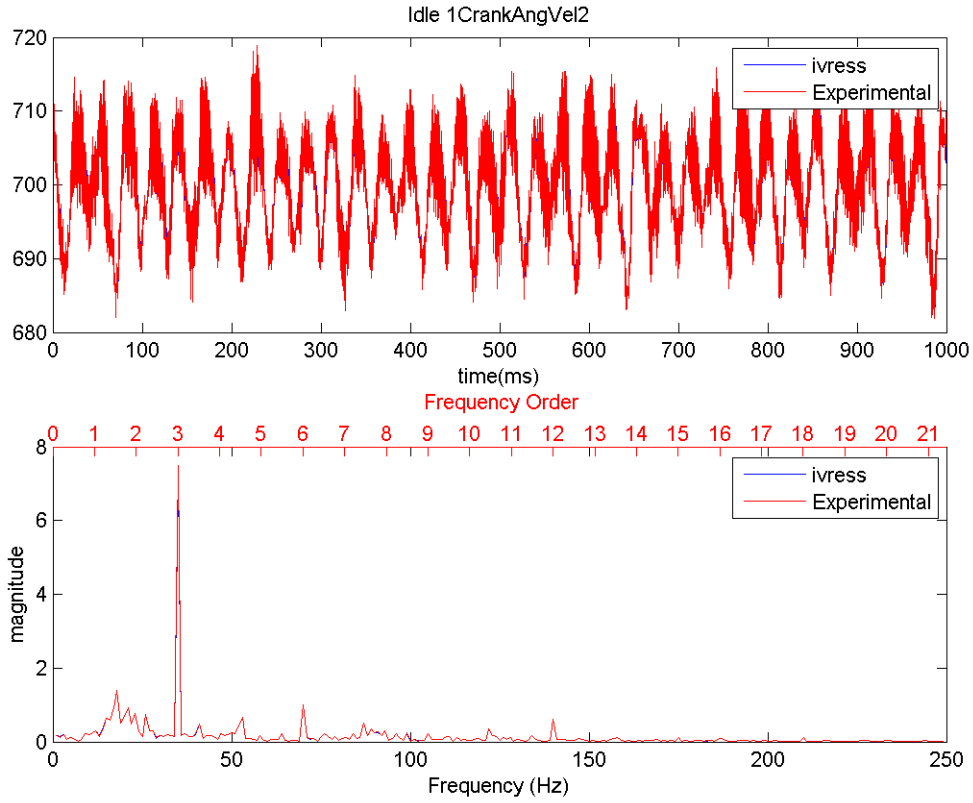

Figure 136 Crankshaft angular velocity in the idle operation range with belt coefficient of friction decreased to 0.4 instead of 0.6 in the baseline

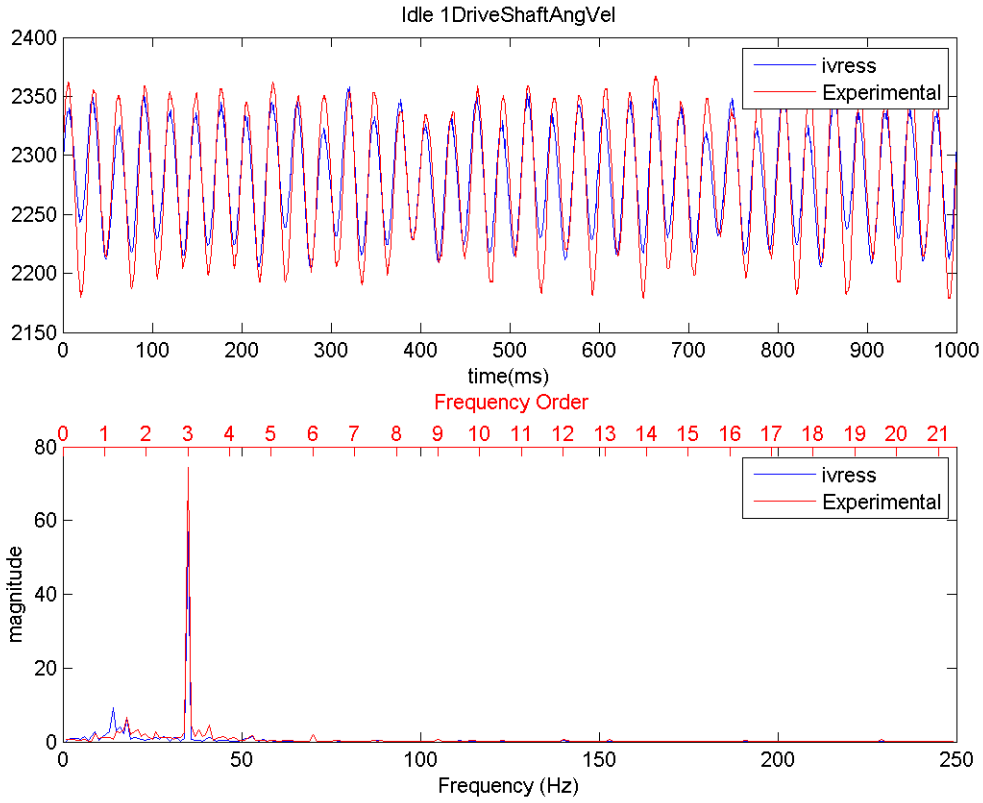

Figure 137 Drive shaft angular velocity in the idle operation range with belt coefficient of friction decreased to 0.4 instead of 0.6 in the baseline

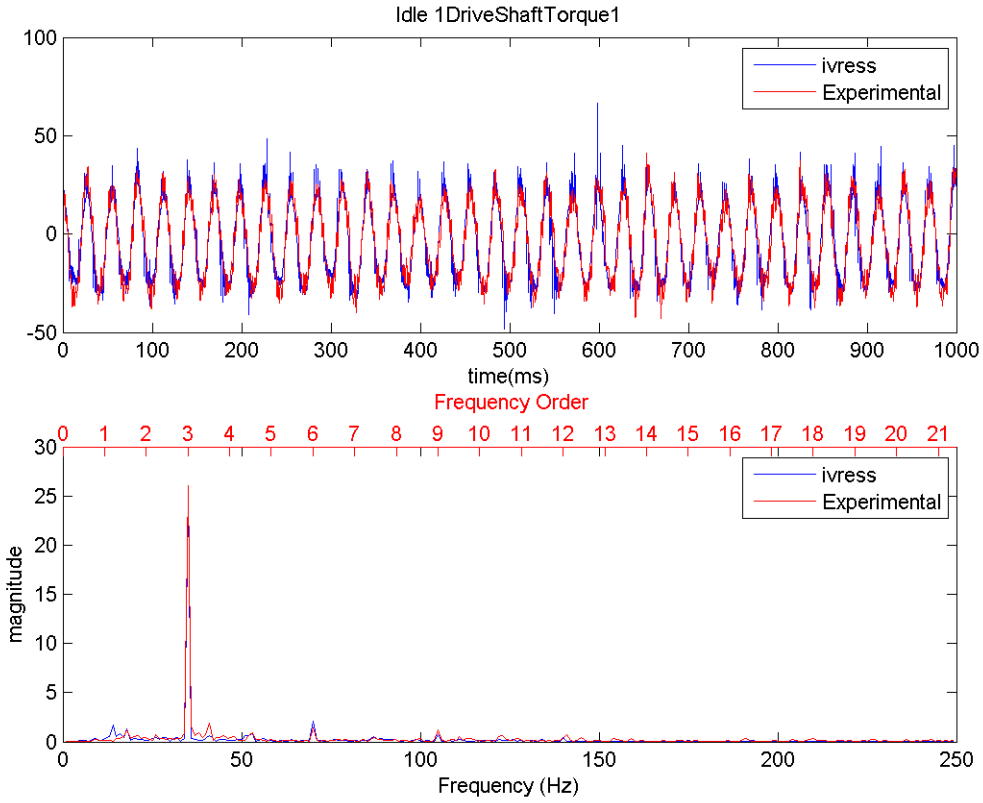

Figure 138 Drive shaft torque in the idle operation range with belt coefficient of friction decreased to 0.4 instead of 0.6 in the baseline

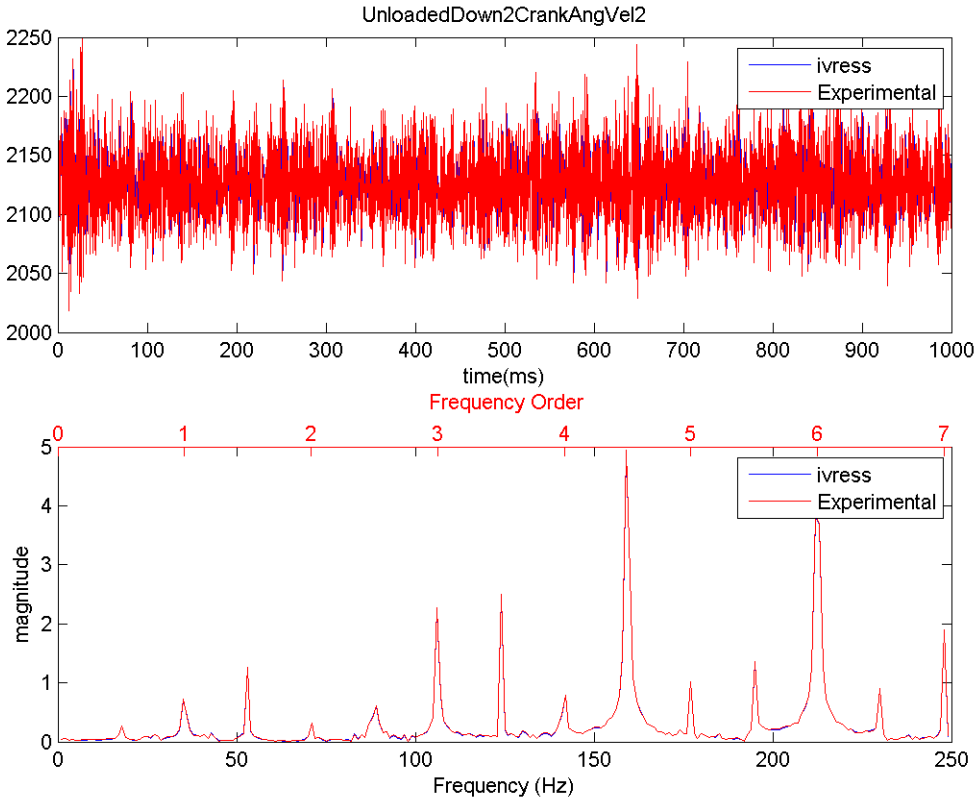

Figure 139 Crankshaft angular velocity in the UnloadedDown operation range with belt coefficient of friction decreased to 0.4 instead of 0.6 in the baseline

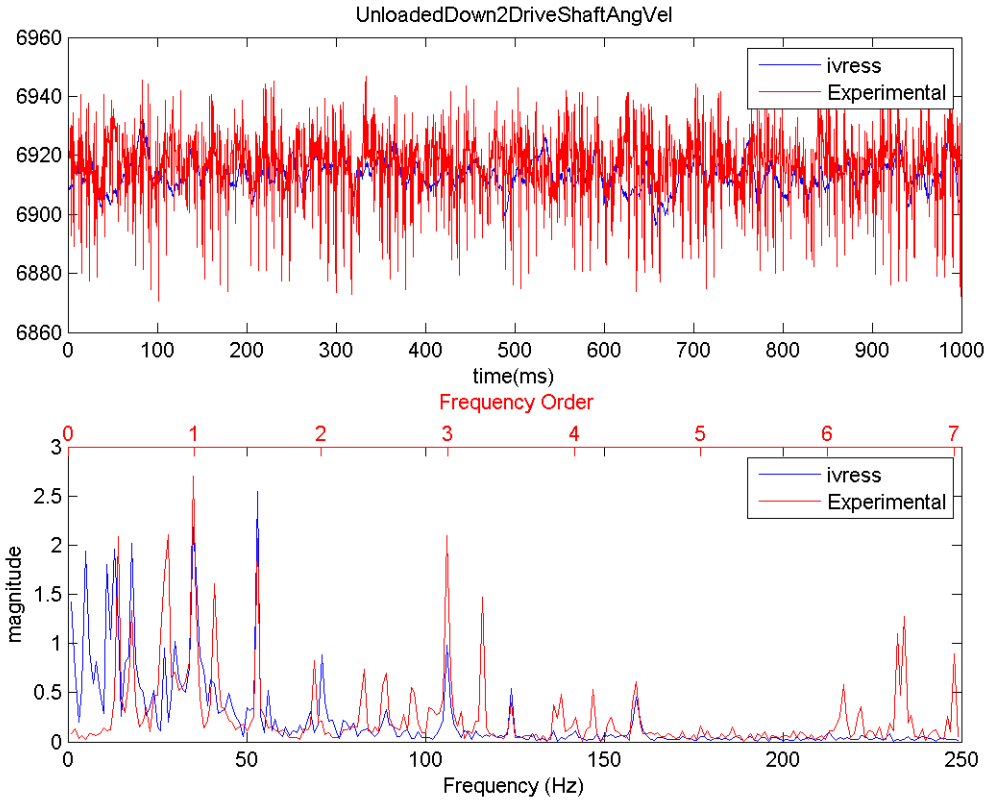

Figure 140 Drive shaft angular velocity in the UnloadedDown operation range with belt coefficient of friction decreased to 0.4 instead of 0.6 in the baseline

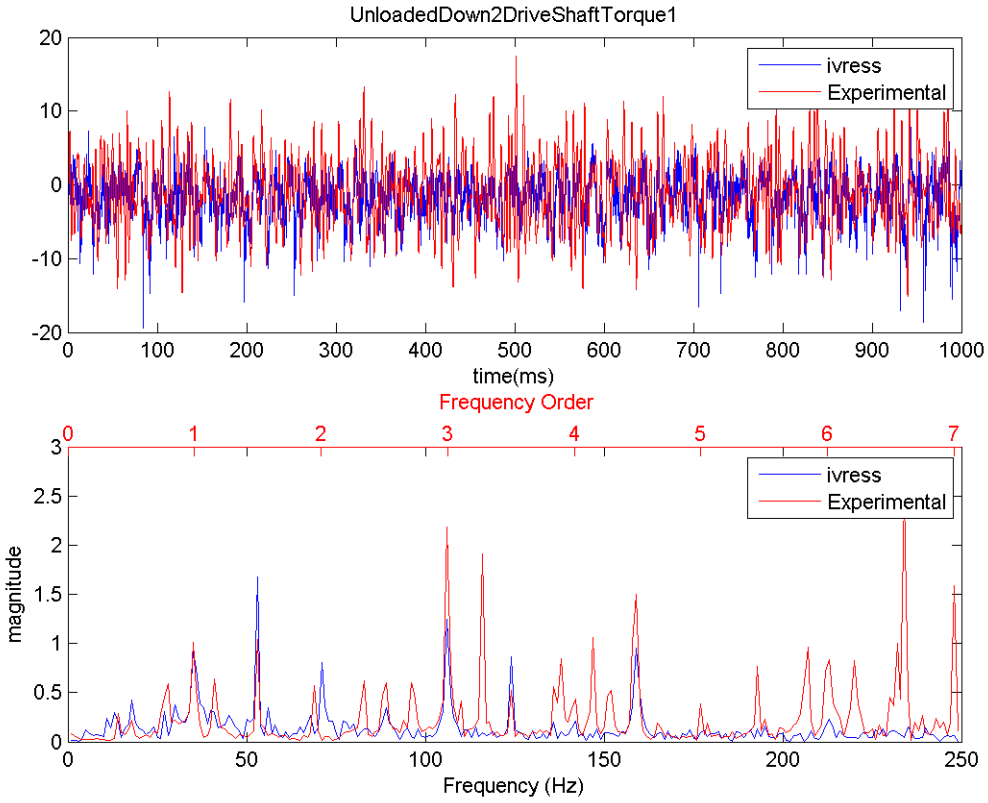

Figure 141 Drive shaft torque in the UnloadedDown operation range with belt coefficient of friction decreased to 0.4 instead of 0.6 in the baseline

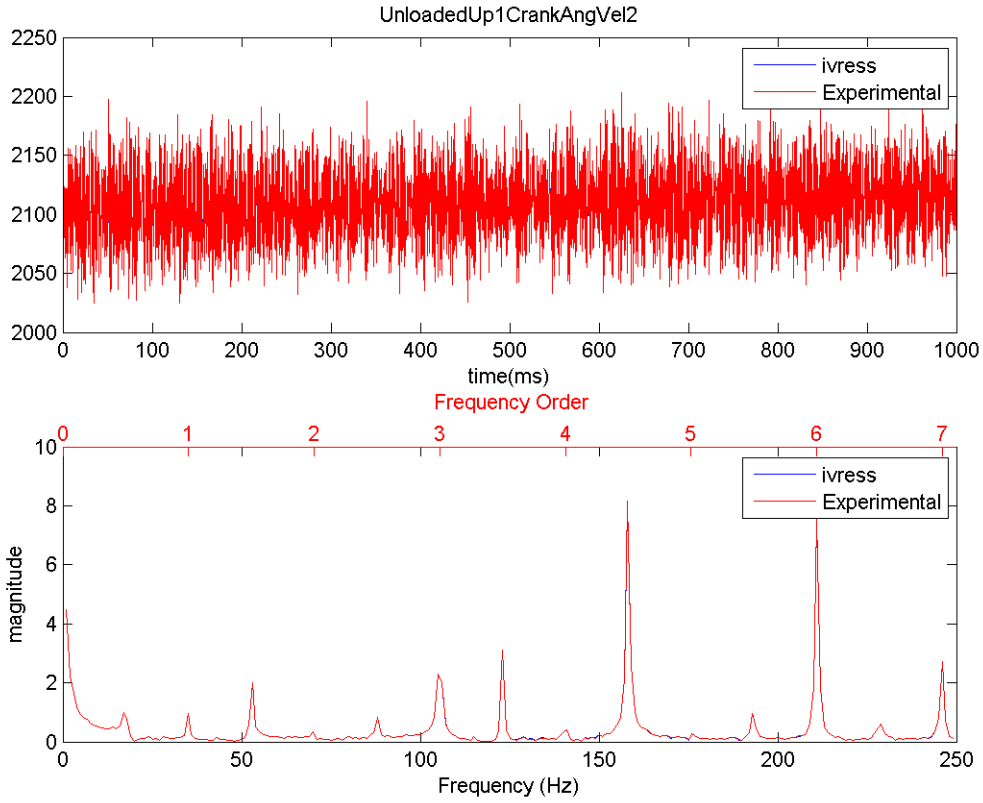

Figure 142 Crankshaft angular velocity in the UnloadedUp operation range with belt coefficient of friction decreased to 0.4 instead of 0.6 in the baseline

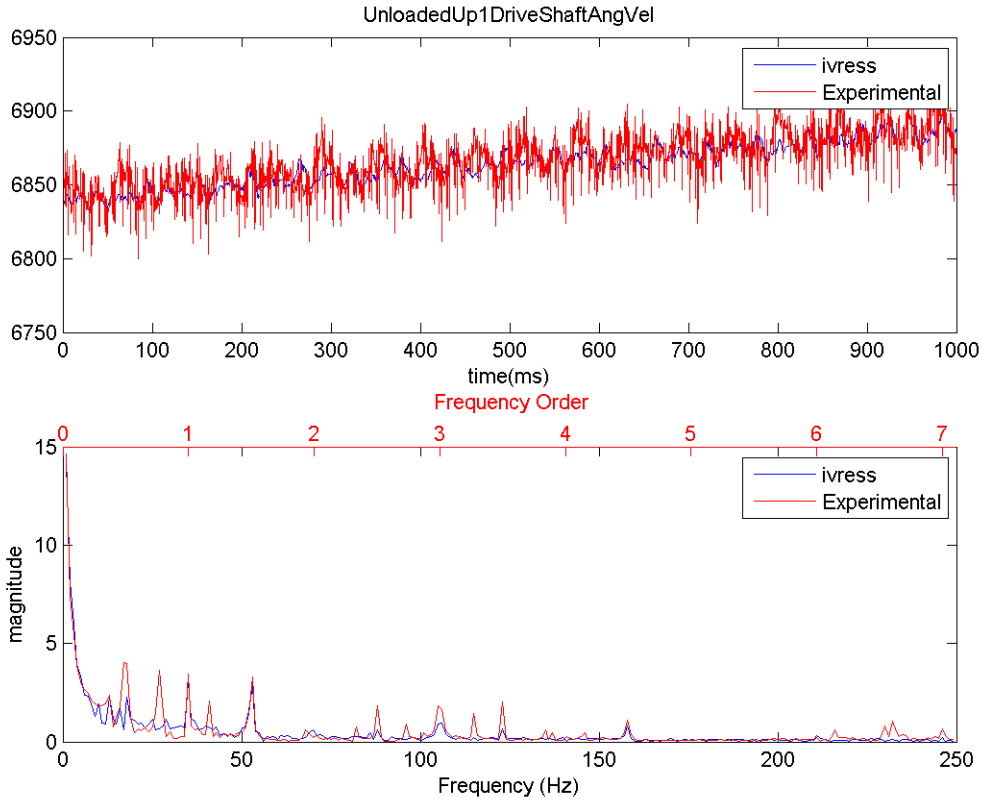

Figure 143 Drive shaft angular velocity in the UnloadedUp operation range with belt coefficient of friction decreased to 0.4 instead of 0.6 in the baseline

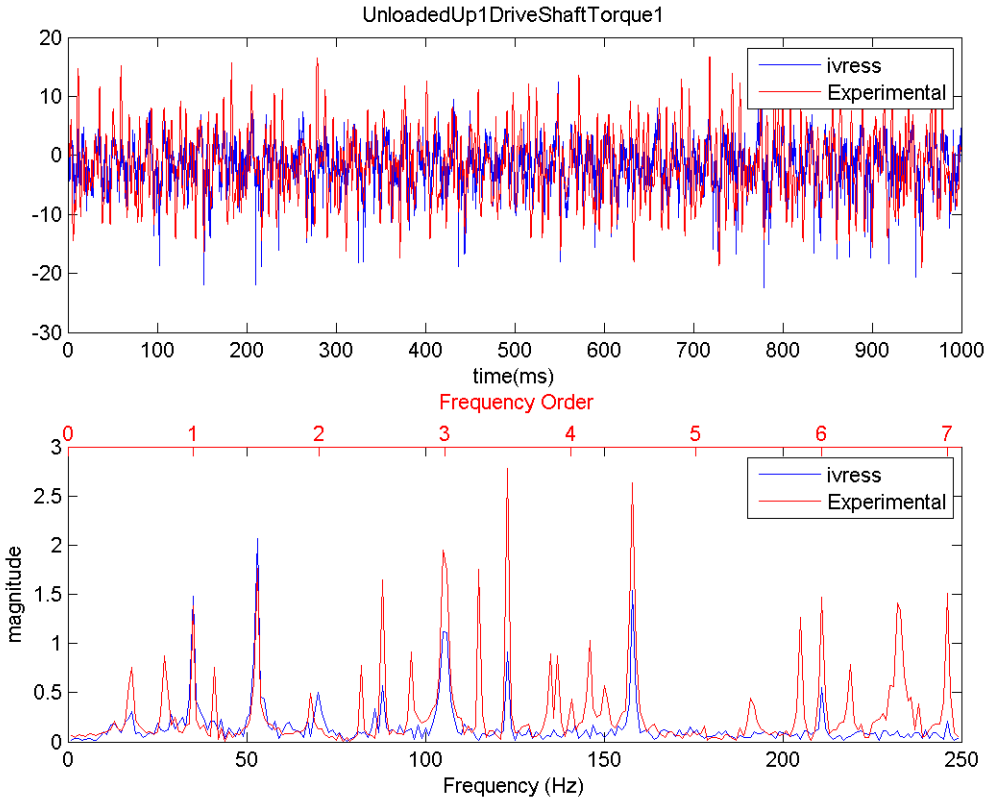

Figure 144 Drive shaft torque in the UnloadedUp operation range with belt coefficient of friction decreased to 0.4 instead of 0.6 in the baseline

9 Pinion Tooth Backlash Increased To $\mathbf{25 \times 10^{-5} m}$ Instead Of $\mathbf{5 \times 10^{-5} m}$ In The Baseline

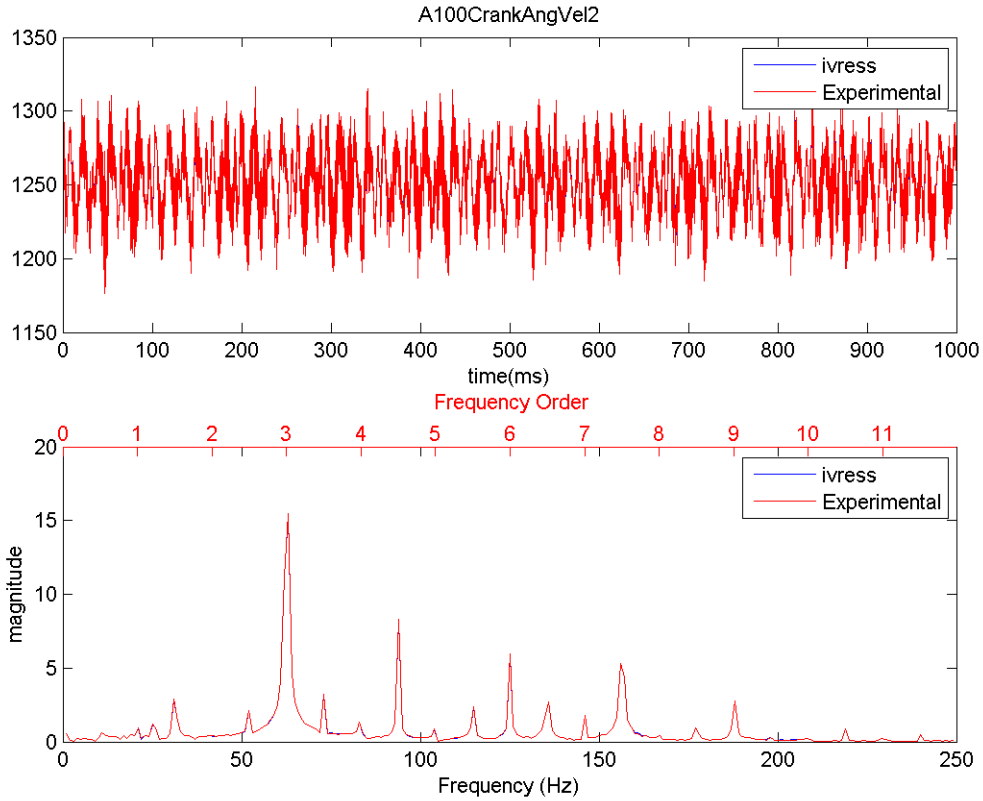

Figure 145 Crankshaft angular velocity in the A100 operation range with pinion tooth backlash increased to $25 \times 10^{-5} m$ instead of $5 \times 10^{-5} m$ in the baseline

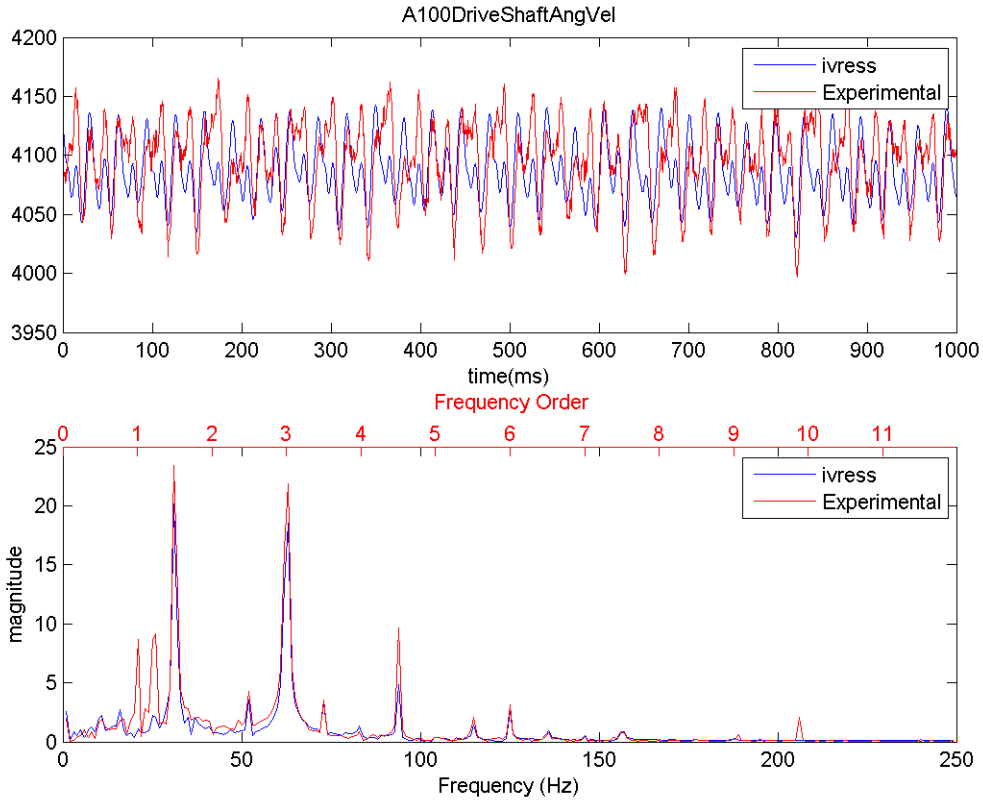

Figure 146 Drive shaft angular velocity in the A100 operation range with pinion tooth backlash increased to $25 \times 10^{-5}m$ instead of $5 \times 10^{-5}m$ in the baseline

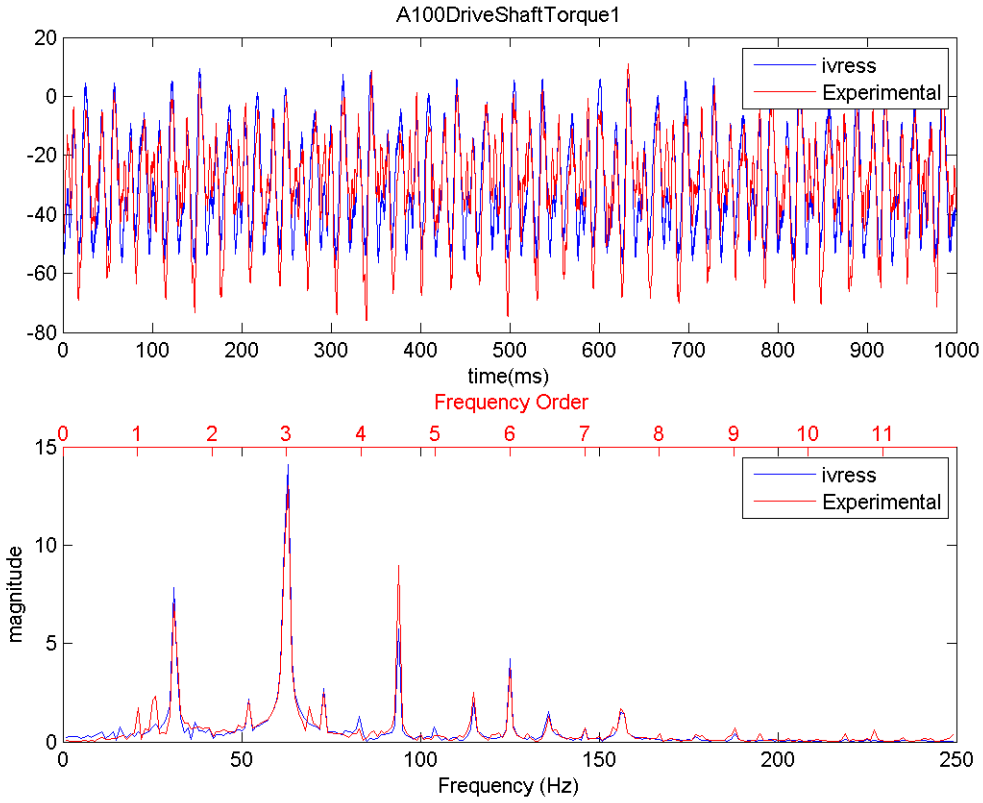

Figure 147 Drive shaft torque in the A100 operation range with pinion tooth backlash increased to $25 \times 10^{-5}m$ instead of $5 \times 10^{-5}m$ in the baseline

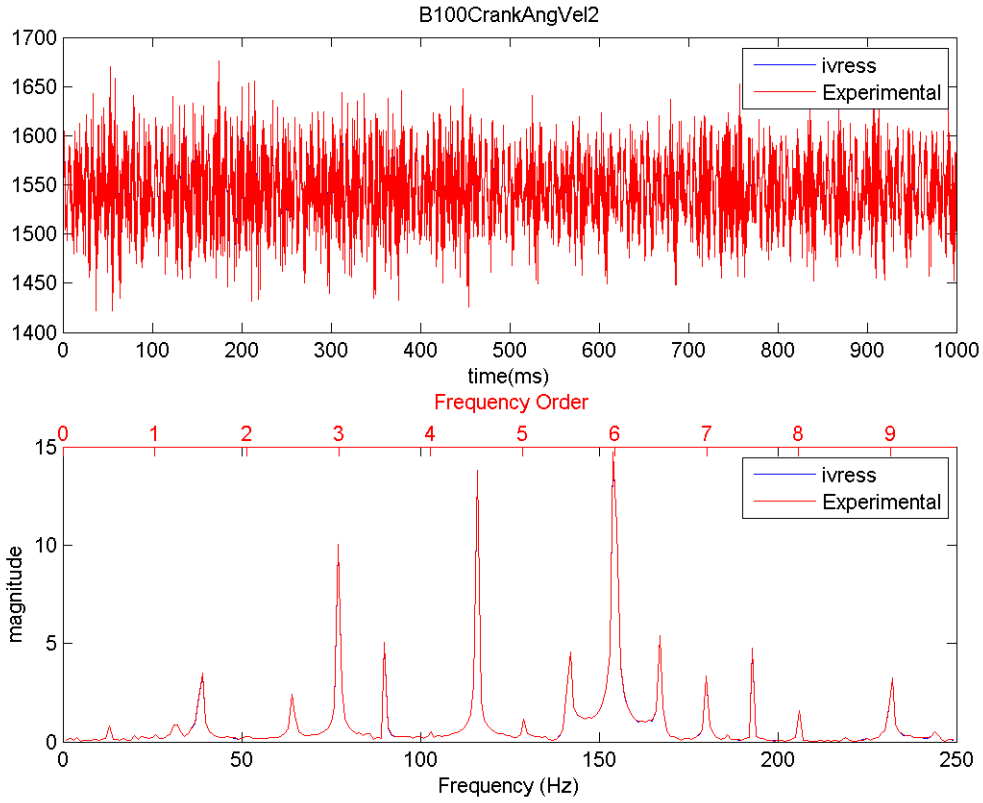

Figure 148 Crankshaft angular velocity in the B100 operation range with pinion tooth backlash increased to $25 \times 10^{-5}m$ instead of $5 \times 10^{-5}m$ in the baseline

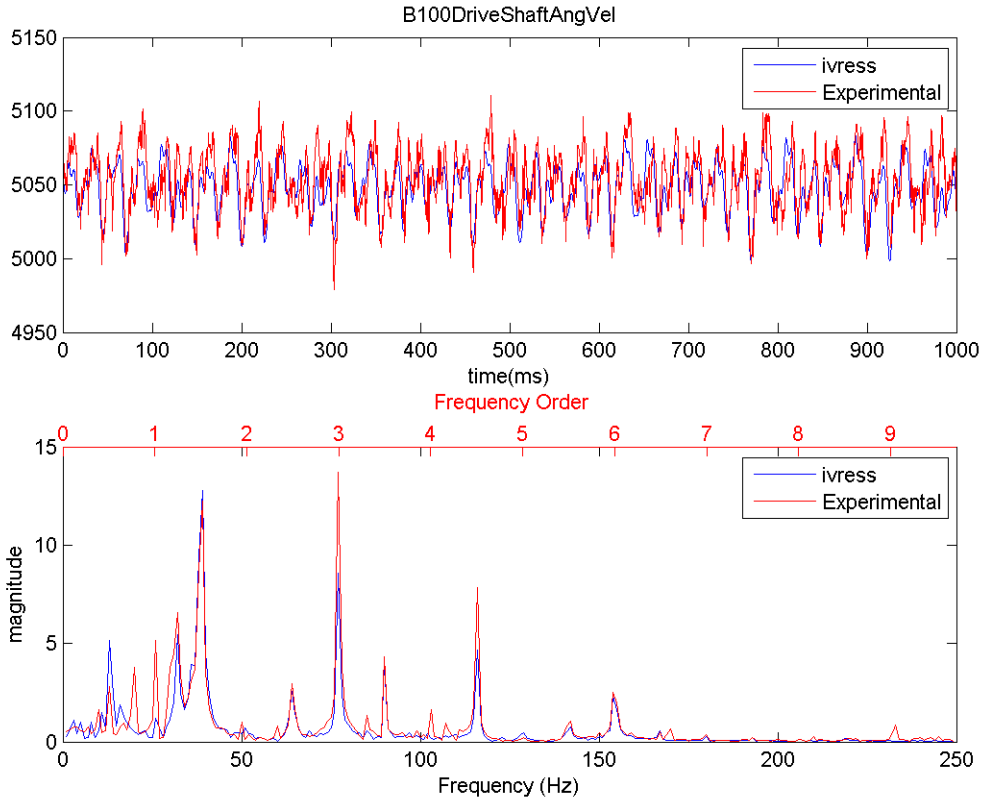

Figure 149 Drive shaft angular velocity in the B100 operation range with pinion tooth backlash increased to $25 \times 10^{-5}m$ instead of $5 \times 10^{-5}m$ in the baseline

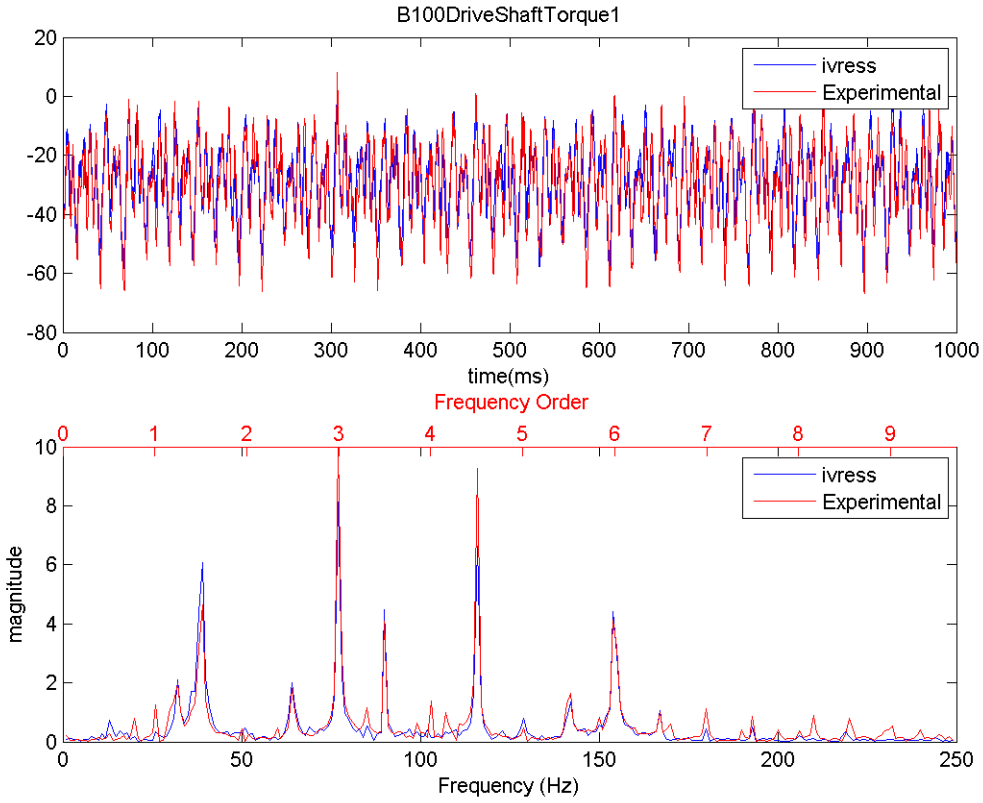

Figure 150 Drive shaft torque in the B100 operation range with pinion tooth backlash increased to $25 \times 10^{-5} m$ instead of $5 \times 10^{-5} m$ in the baseline

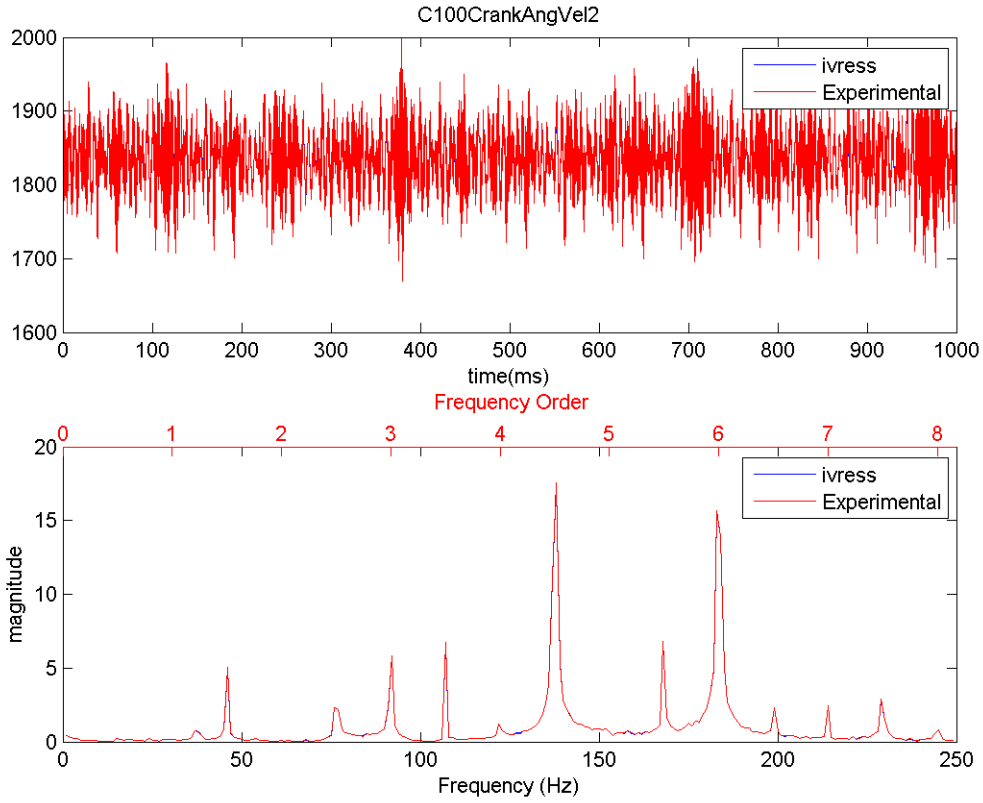

Figure 151 Crankshaft angular velocity in the C100 operation range with pinion tooth backlash increased to $25 \times 10^{-5}m$ instead of $5 \times 10^{-5}m$ in the baseline

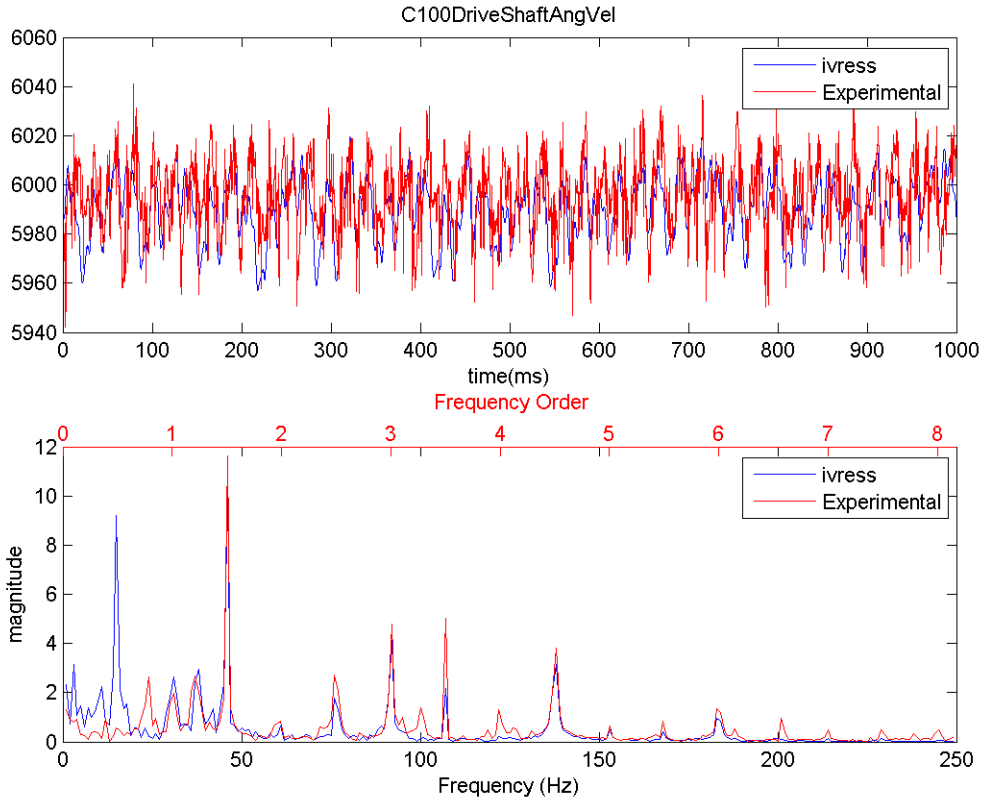

Figure 152 Drive shaft angular velocity in the C100 operation range with pinion tooth backlash increased to $25 \times 10^{-5}m$ instead of $5 \times 10^{-5}m$ in the baseline

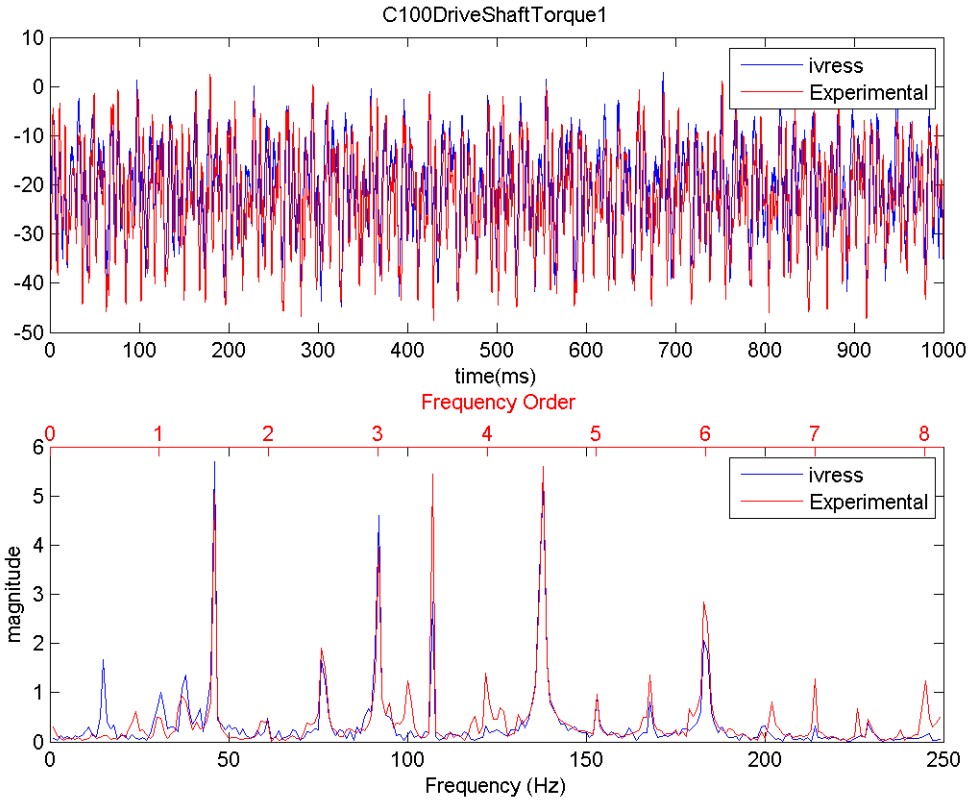

Figure 153 Drive shaft torque in the C100 operation range with pinion tooth backlash increased to $25 \times 10^{-5}m$ instead of $5 \times 10^{-5}m$ in the baseline

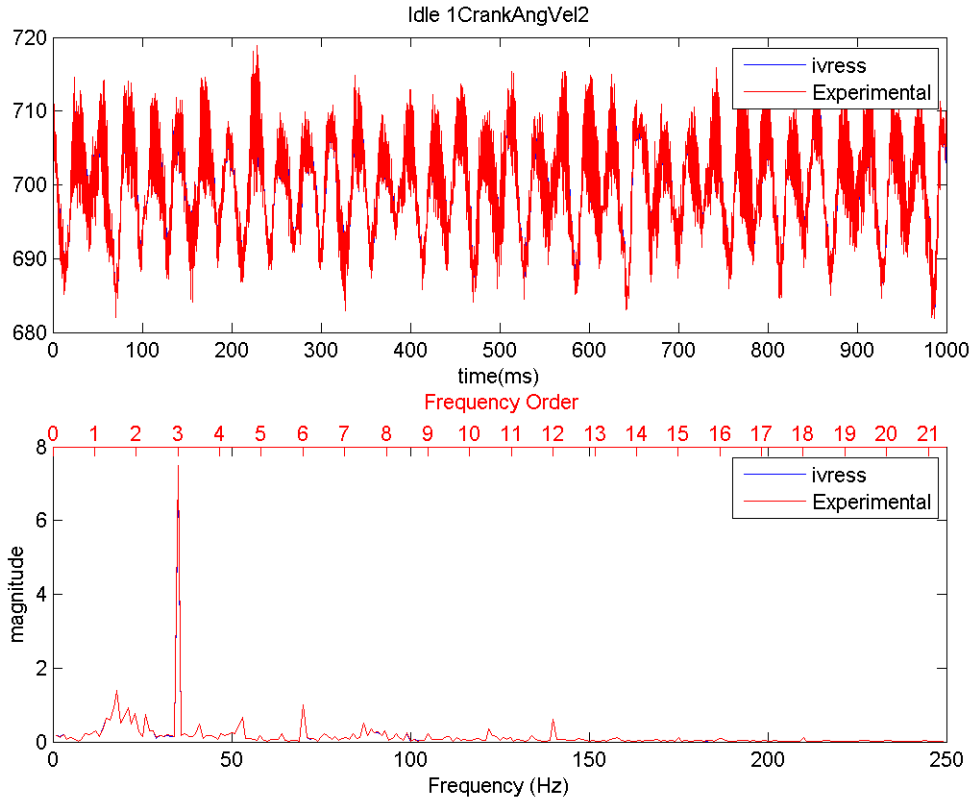

Figure 154 Crankshaft angular velocity in the idle operation range with pinion tooth backlash increased to $25 \times 10^{-5}m$ instead of $5 \times 10^{-5}m$ in the baseline

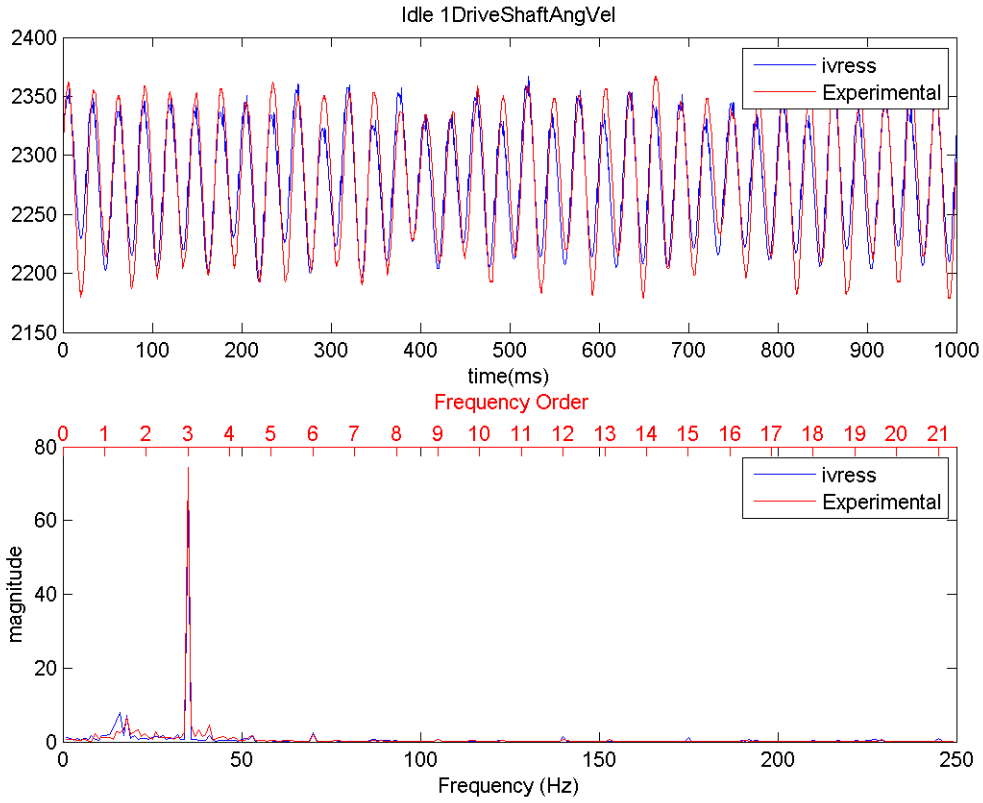

Figure 155 Drive shaft angular velocity in the idle operation range with pinion tooth backlash increased to $25 \times 10^{-5}m$ instead of $5 \times 10^{-5}m$ in the baseline

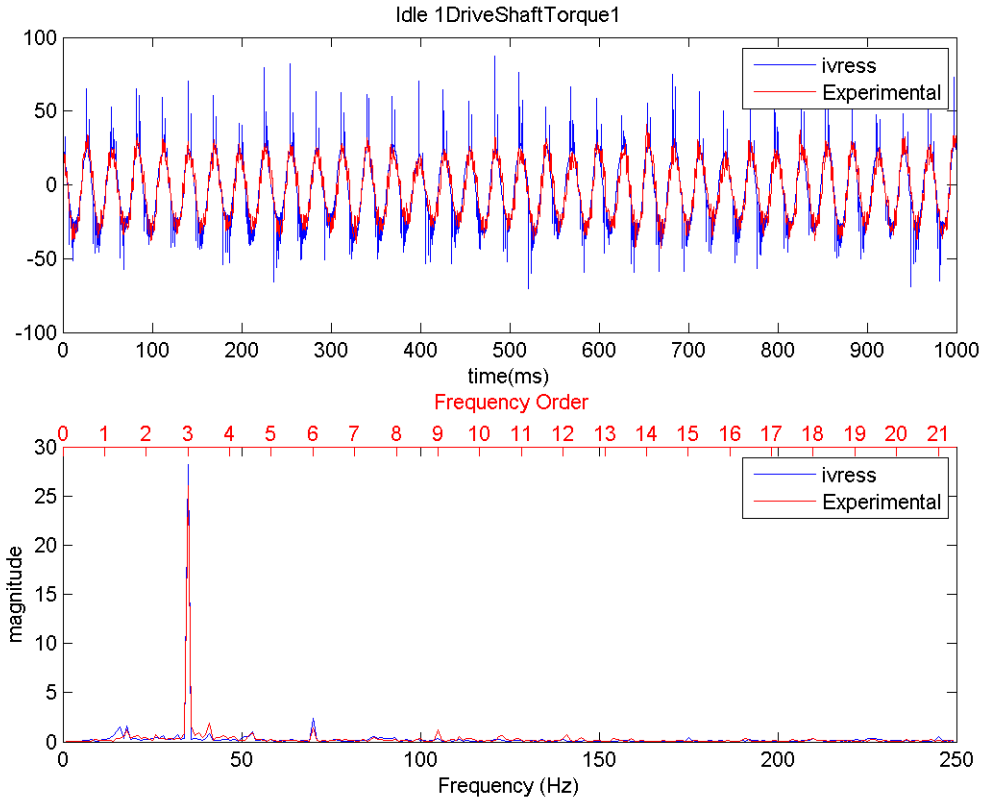

Figure 156 Drive shaft torque in the idle operation range with pinion tooth backlash increased to $25 \times 10^{-5}m$ instead of $5 \times 10^{-5}m$ in the baseline

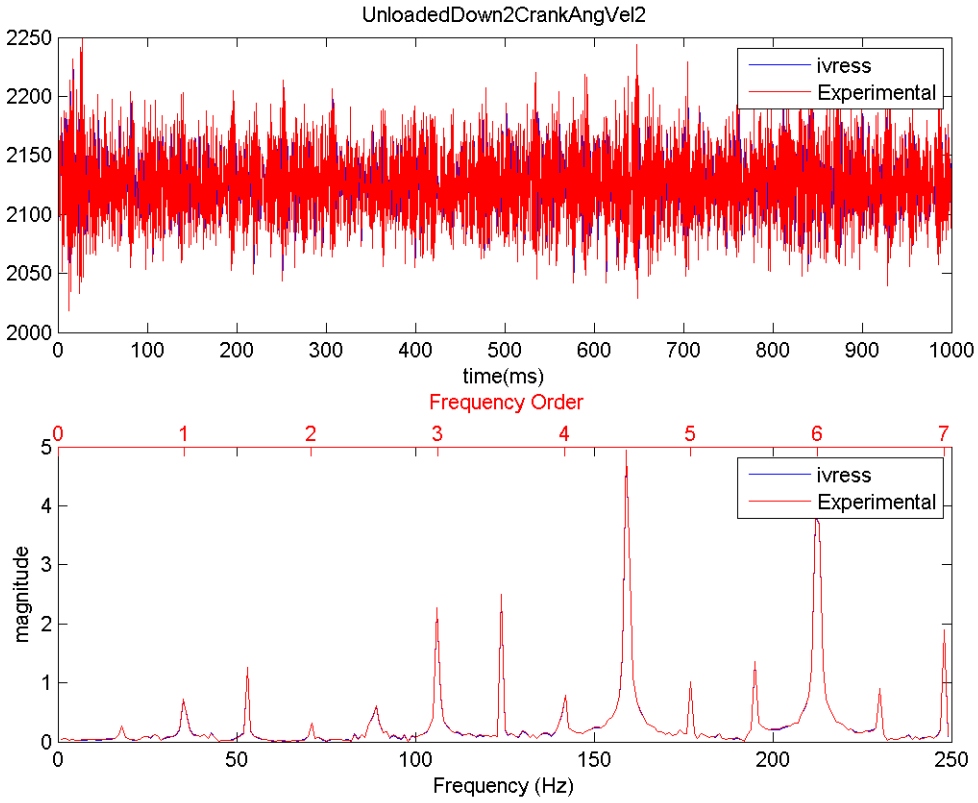

Figure 157 Crankshaft angular velocity in the UnloadedDown operation range with pinion tooth backlash increased to $25 \times 10^{-5}m$ instead of $5 \times 10^{-5}m$ in the baseline

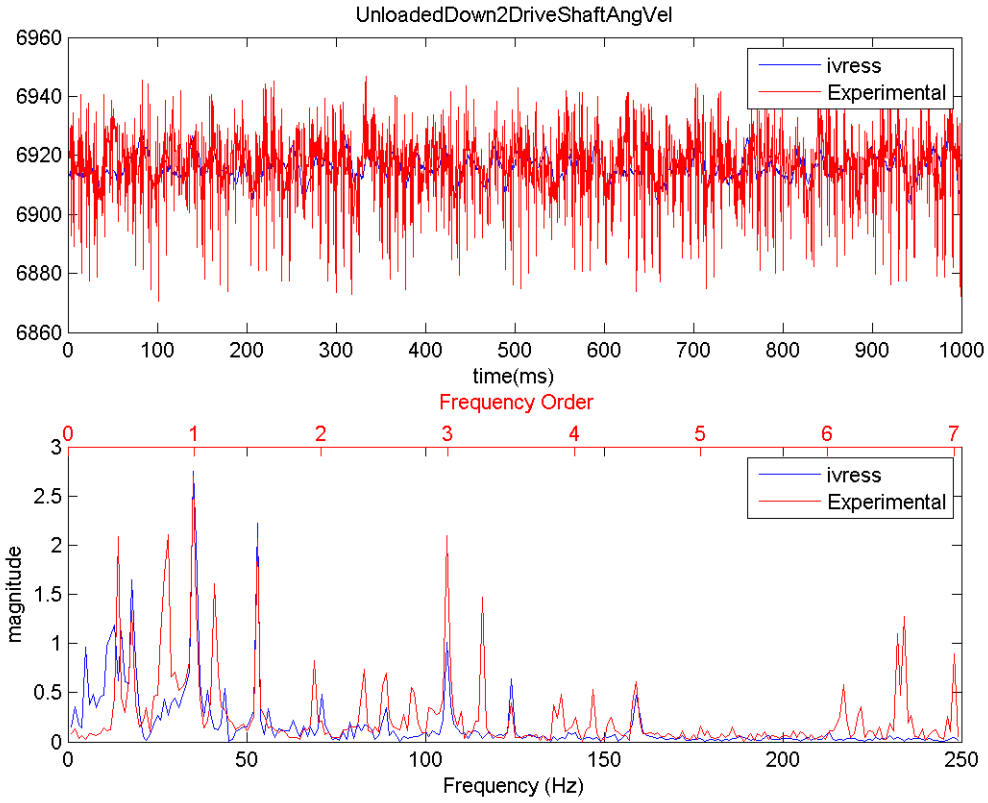

Figure 158 Drive shaft angular velocity in the UnloadedDown operation range with pinion tooth backlash increased to $25 \times 10^{-5}m$ instead of $5 \times 10^{-5}m$ in the baseline

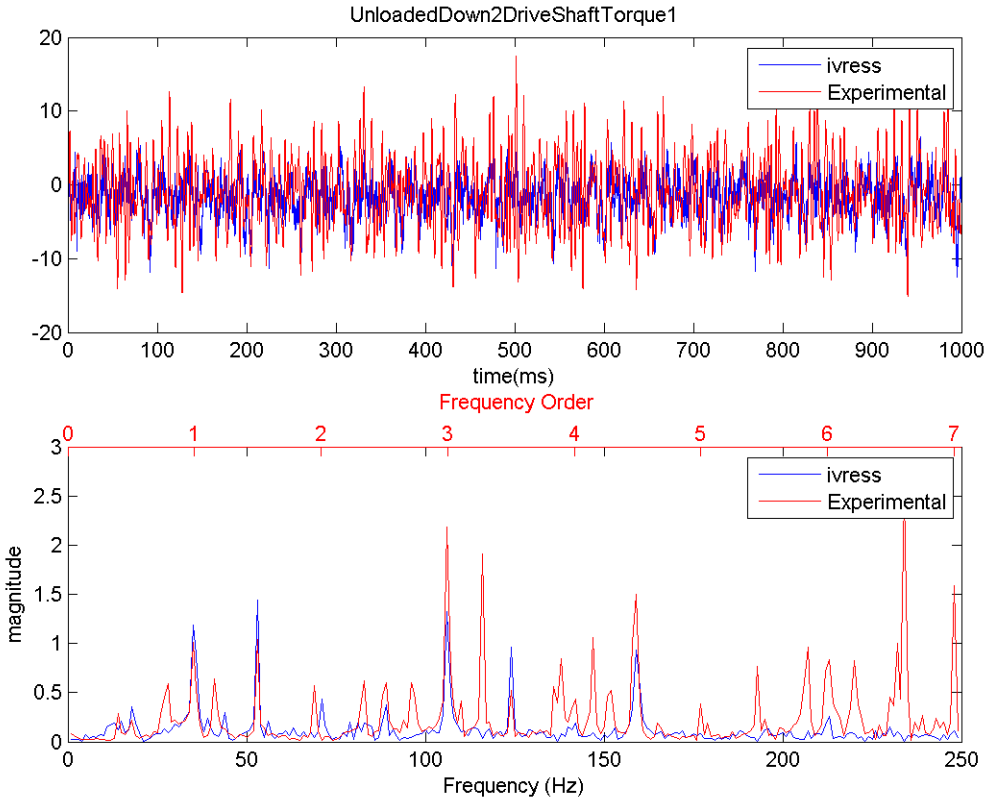

Figure 159 Drive shaft torque in the UnloadedDown operation range with pinion tooth backlash increased to $25 \times 10^{-5}m$ instead of $5 \times 10^{-5}m$ in the baseline

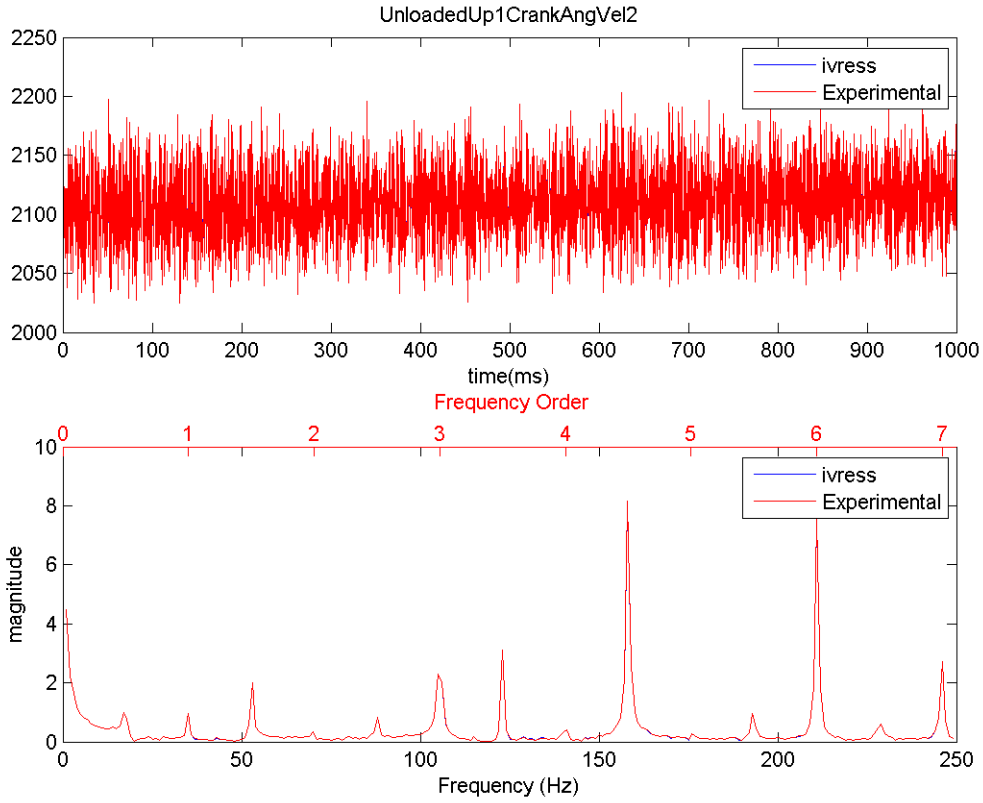

Figure 160 Crankshaft angular velocity in the UnloadedUp operation range with pinion tooth backlash increased to $25 \times 10^{-5}m$ instead of $5 \times 10^{-5}m$ in the baseline

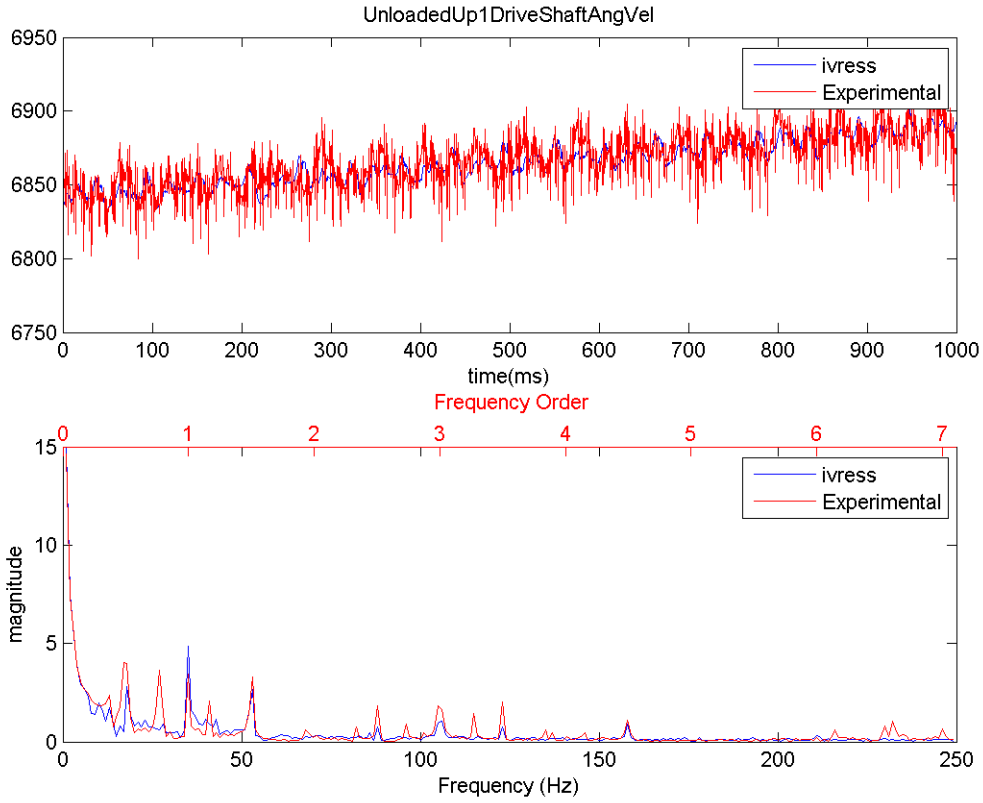

Figure 161 Drive shaft angular velocity in the UnloadedUp operation range with pinion tooth backlash increased to $25 \times 10^{-5}m$ instead of $5 \times 10^{-5}m$ in the baseline

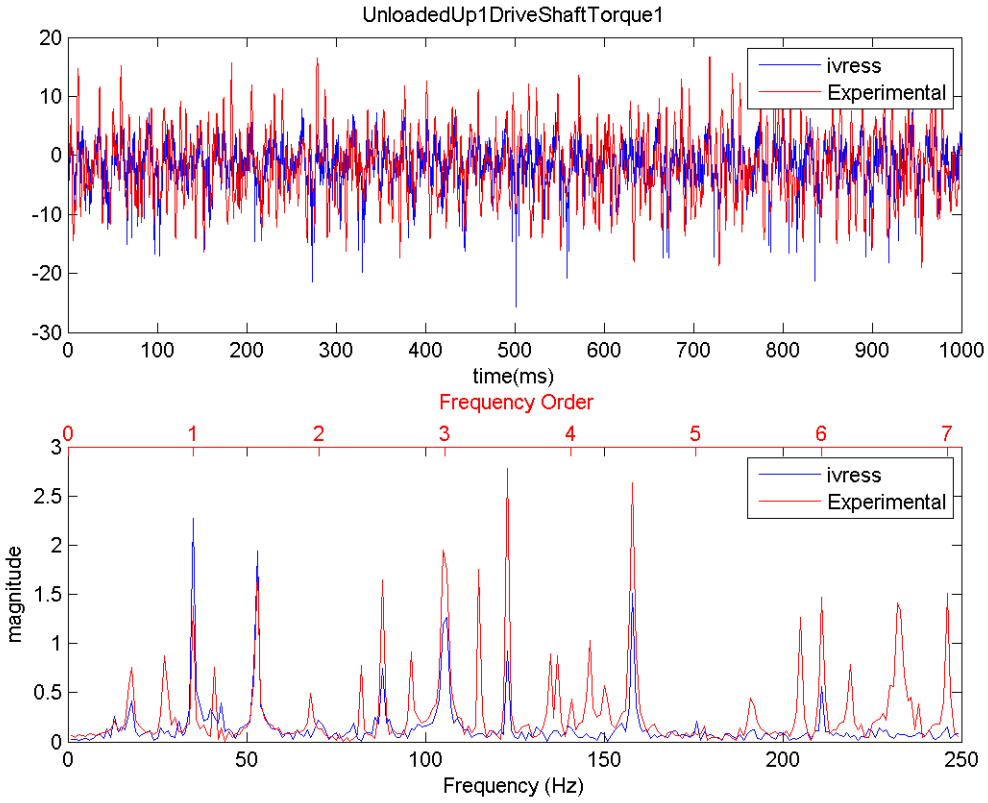

Figure 162 Drive shaft torque in the UnloadedUp operation range with pinion tooth backlash increased to $25 \times 10^{-5}m$ instead of $5 \times 10^{-5}m$ in the baseline

10 Pinion Tooth Stiffness Increased To $4 \times 10^{13} N/m$ Instead Of $2 \times 10^{13} N/m$ In The Baseline

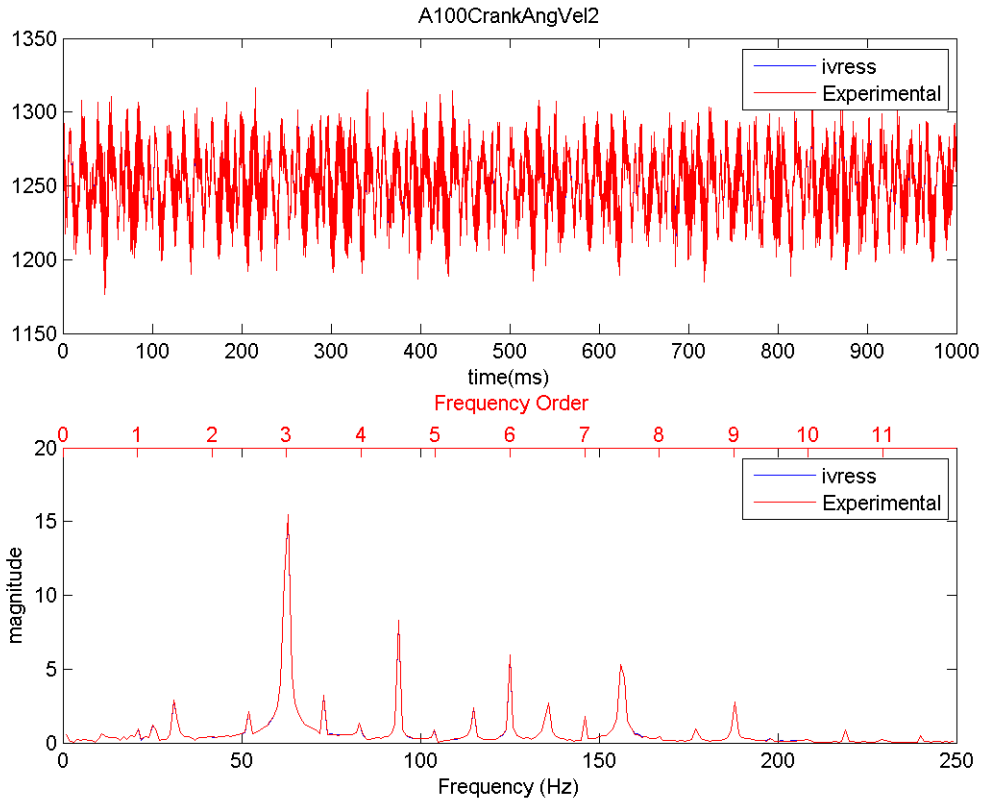

Figure 163 Crankshaft angular velocity in the A100 operation range with pinion tooth stiffness increased to $4 \times 10^{13} N/m$ instead of $2 \times 10^{13} N/m$ in the baseline

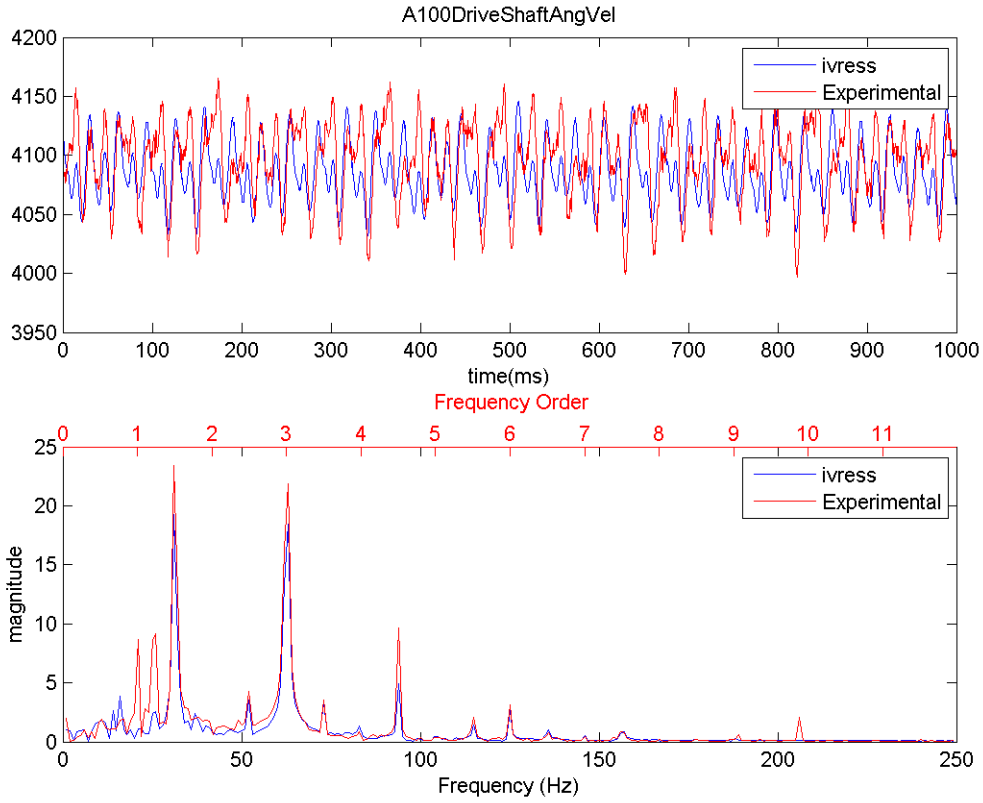

Figure 164 Drive shaft angular velocity in the A100 operation range with pinion tooth stiffness increased to $4 \times 10^{13} N/m$ instead of $2 \times 10^{13} N/m$ in the baseline

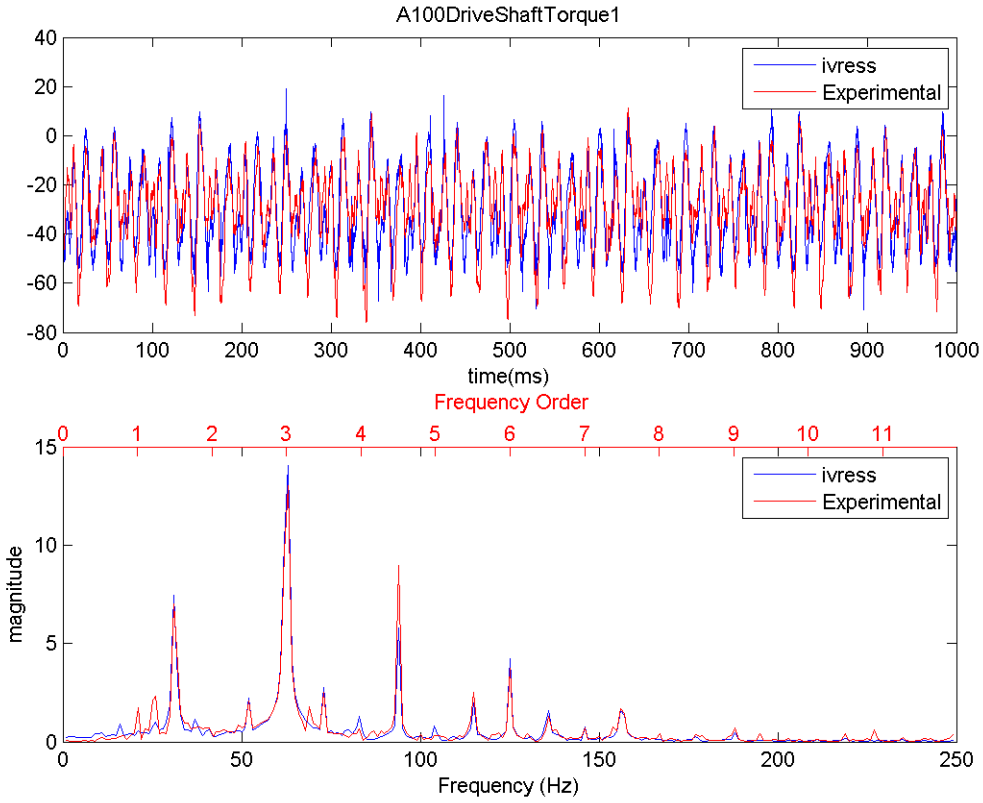

Figure 165 Drive shaft torque in the A100 operation range with pinion tooth stiffness increased to $4 \times 10^{13} N/m$ instead of $2 \times 10^{13} N/m$ in the baseline

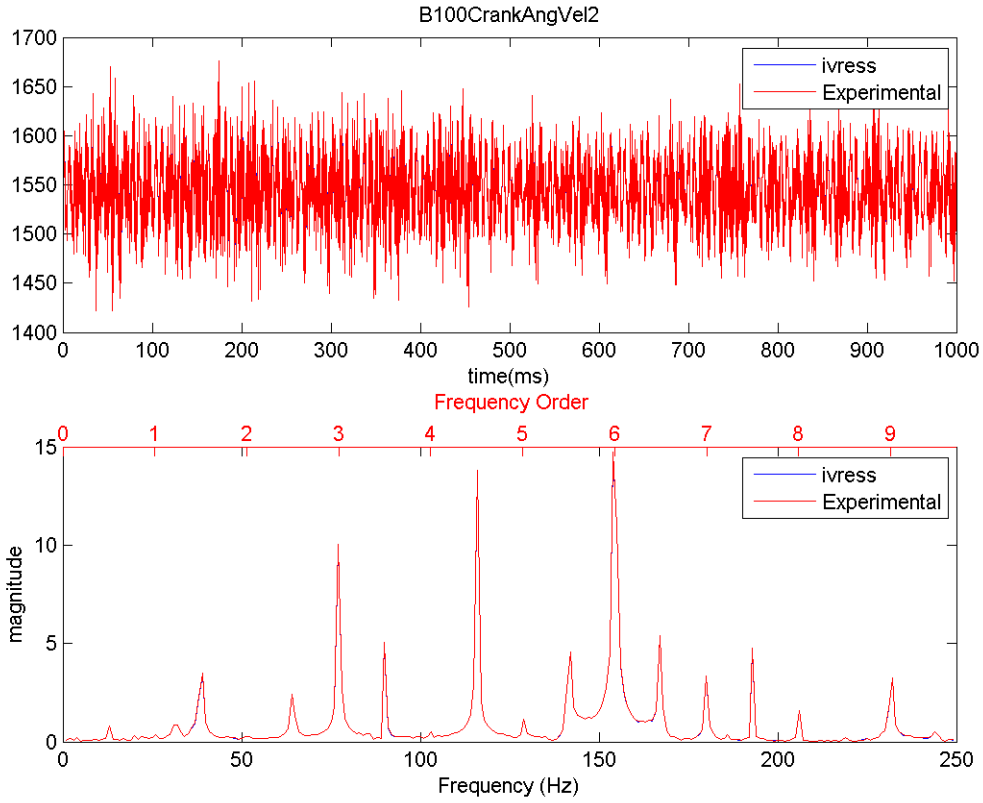

Figure 166 Crankshaft angular velocity in the B100 operation range with pinion tooth stiffness increased to $4 \times 10^{13} N/m$ instead of $2 \times 10^{13} N/m$ in the baseline

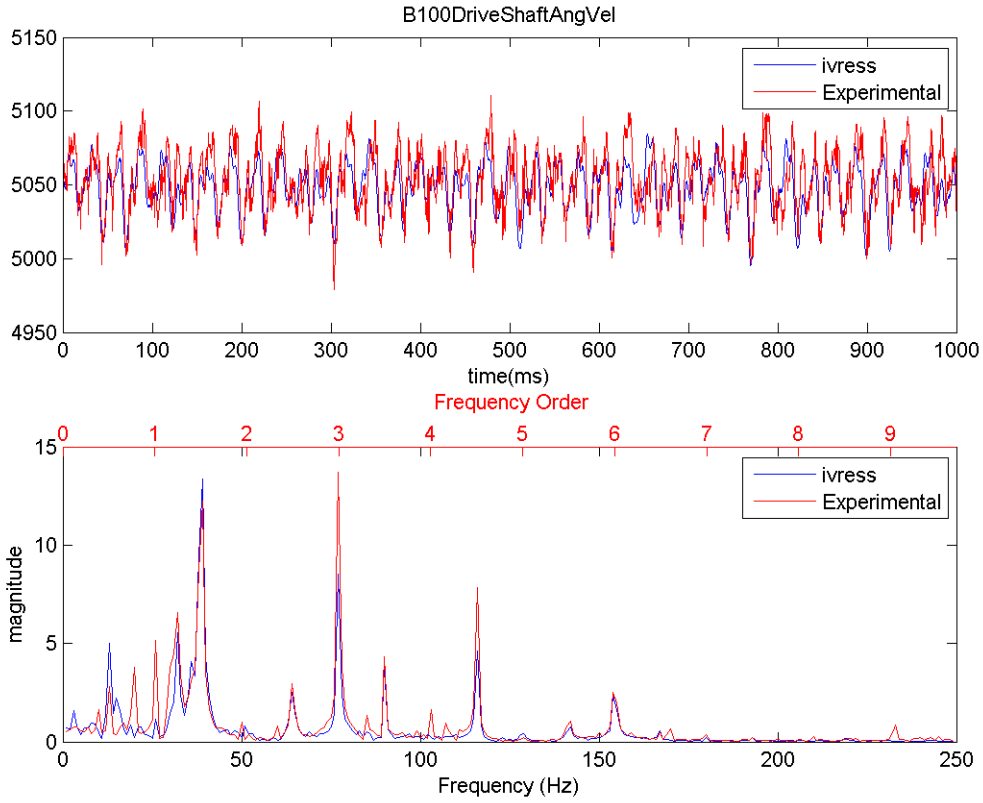

Figure 167 Drive shaft angular velocity in the B100 operation range with pinion tooth stiffness increased to 4×10^{13} N/m instead of 2×10^{13} N/m in the baseline

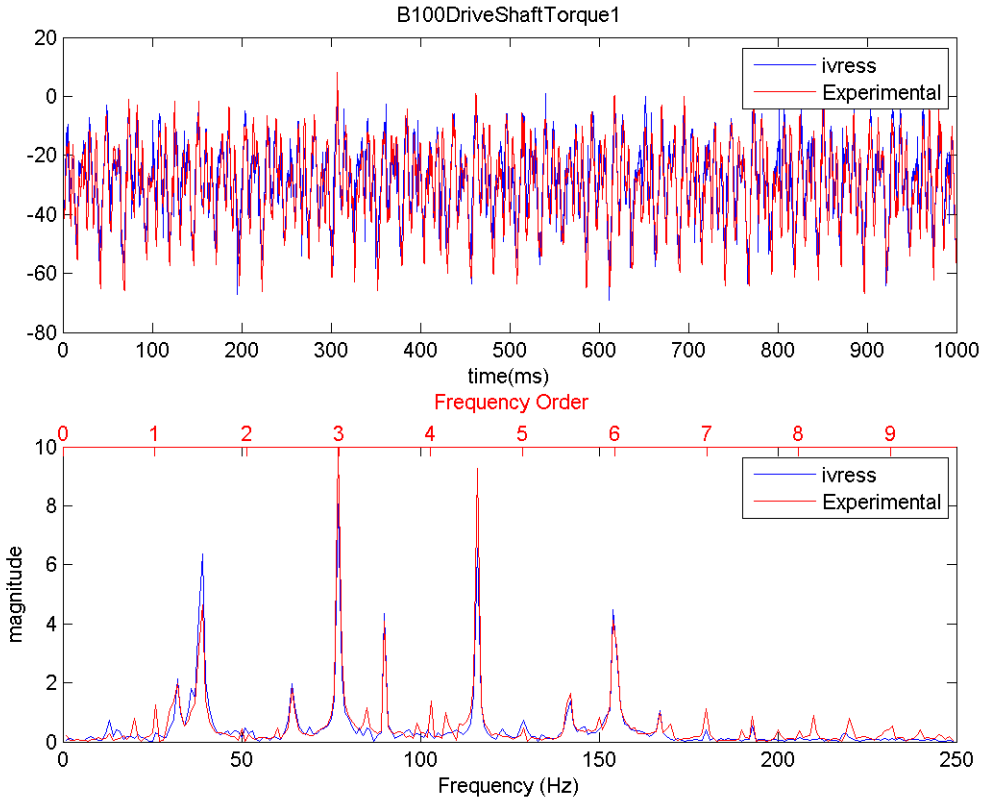

Figure 168 Drive shaft torque in the B100 operation range with pinion tooth stiffness increased to $4 \times 10^{13} N/m$ instead of $2 \times 10^{13} N/m$ in the baseline

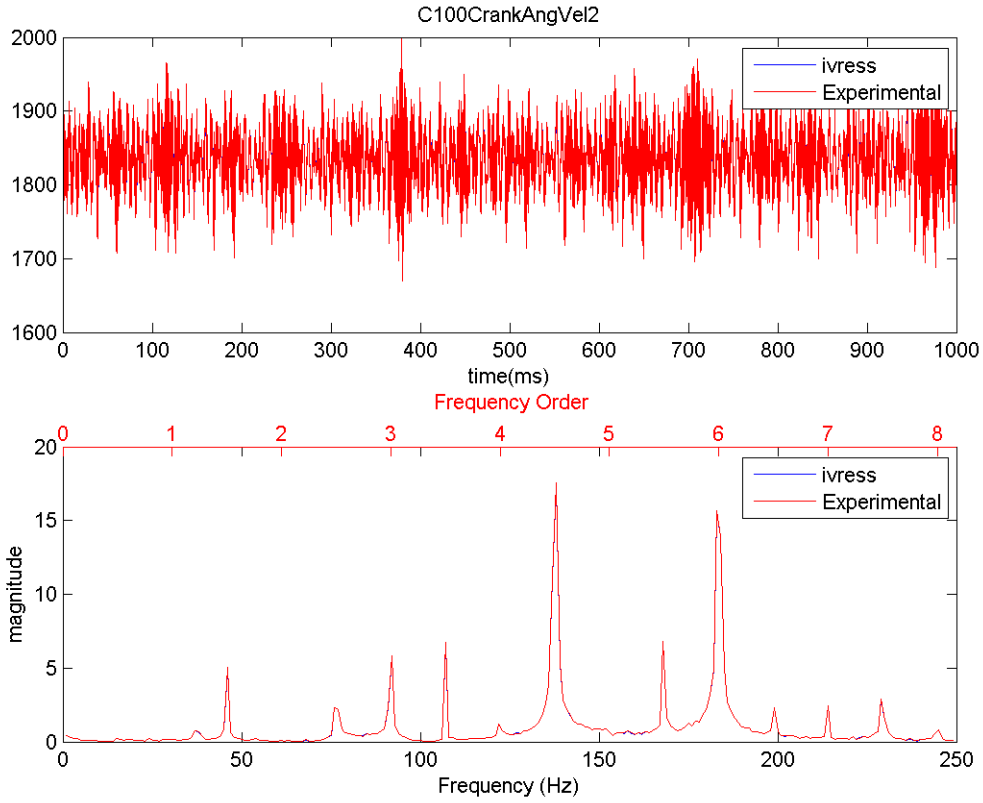

Figure 169 Crankshaft angular velocity in the C100 operation range with pinion tooth stiffness increased to $4 \times 10^{13} N/m$ instead of $2 \times 10^{13} N/m$ in the baseline

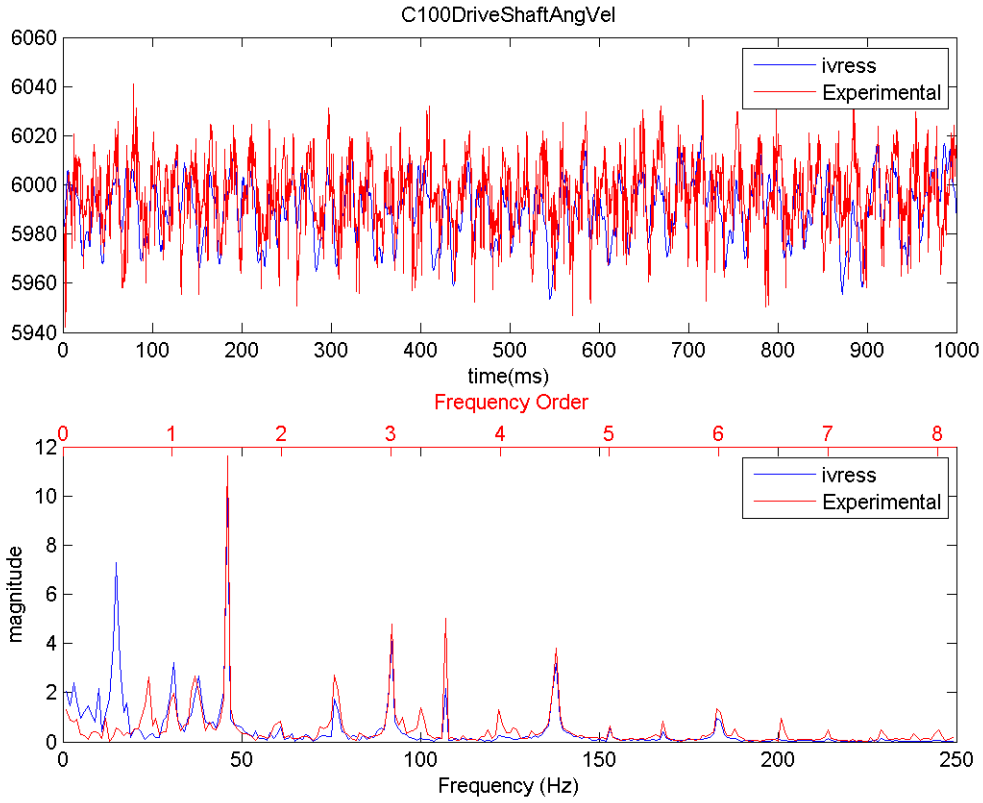

Figure 170 Drive shaft angular velocity in the C100 operation range with pinion tooth stiffness increased to $4 \times 10^{13} N/m$ instead of $2 \times 10^{13} N/m$ in the baseline

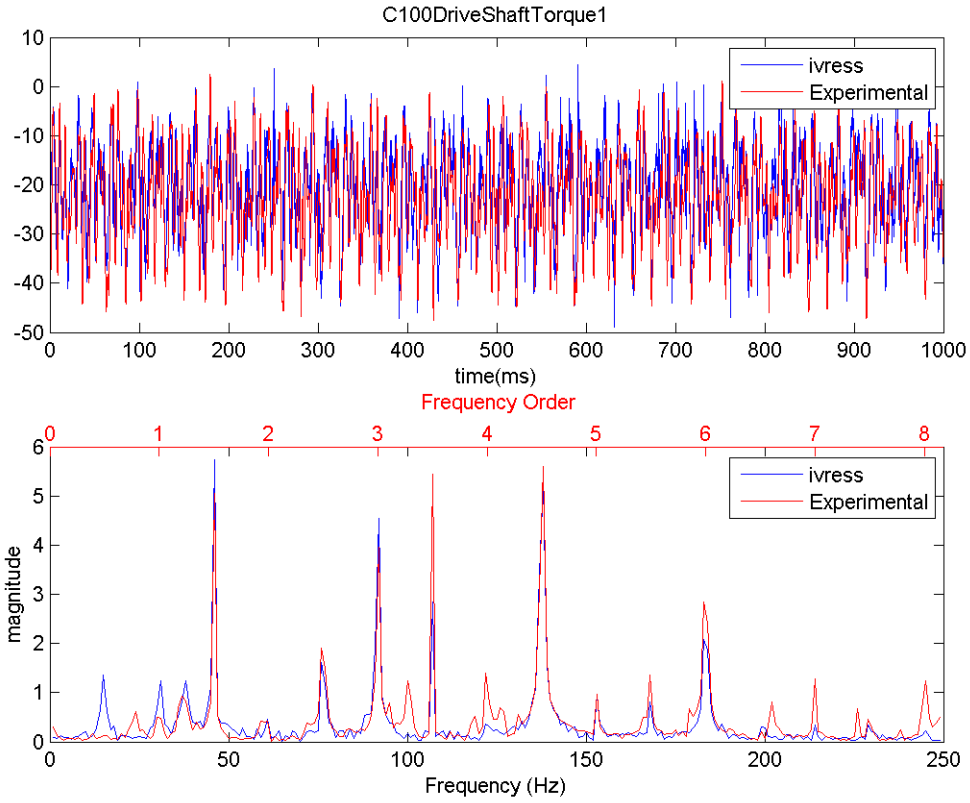

Figure 171 Drive shaft torque in the C100 operation range with pinion tooth stiffness increased to $4 \times 10^{13} N/m$ instead of $2 \times 10^{13} N/m$ in the baseline

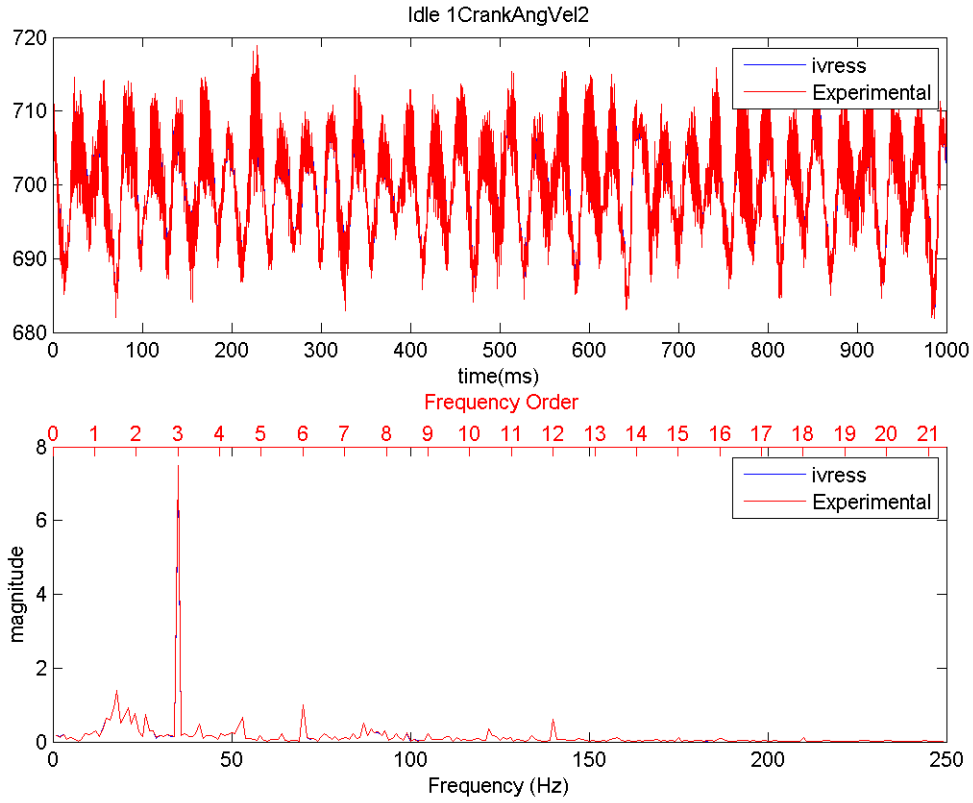

Figure 172 Crankshaft angular velocity in the idle operation range with pinion tooth stiffness increased to $4 \times 10^{13} N/m$ instead of $2 \times 10^{13} N/m$ in the baseline

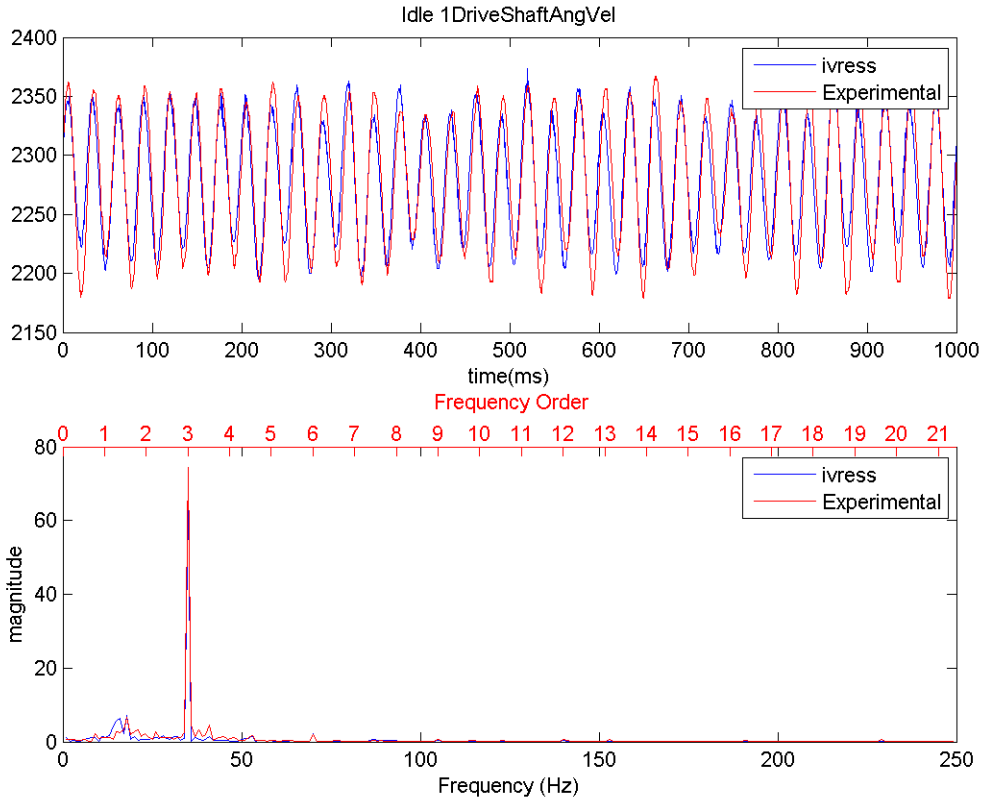

Figure 173 Drive shaft angular velocity in the idle operation range with pinion tooth stiffness increased to $4 \times 10^{13} N/m$ instead of $2 \times 10^{13} N/m$ in the baseline

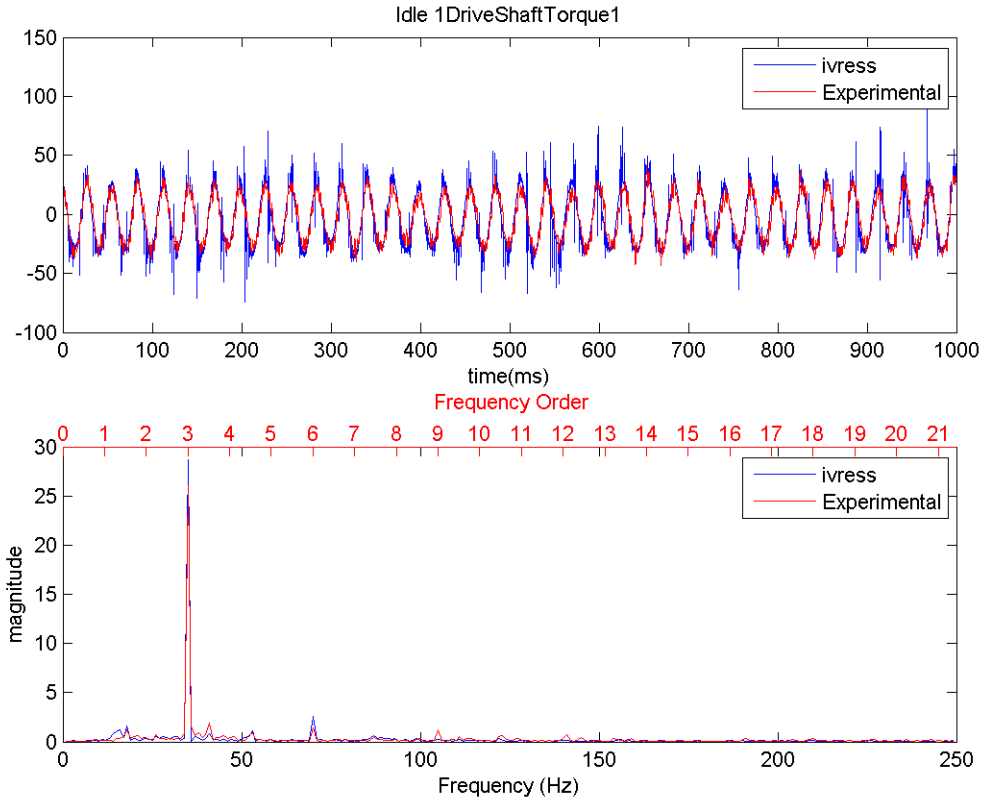

Figure 174 Drive shaft torque in the idle operation range with pinion tooth stiffness increased to $4 \times 10^{13} N/m$ instead of $2 \times 10^{13} N/m$ in the baseline

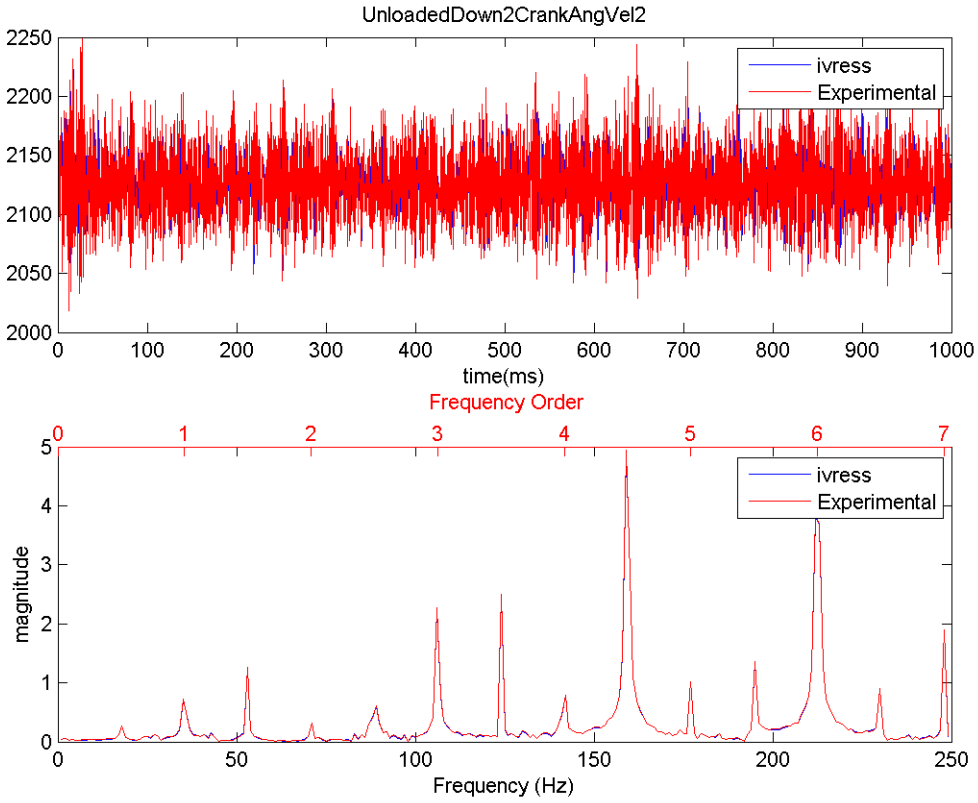

Figure 175 Crankshaft angular velocity in the UnloadedDown operation range with pinion tooth stiffness increased to $4 \times 10^{13} N/m$ instead of $2 \times 10^{13} N/m$ in the baseline

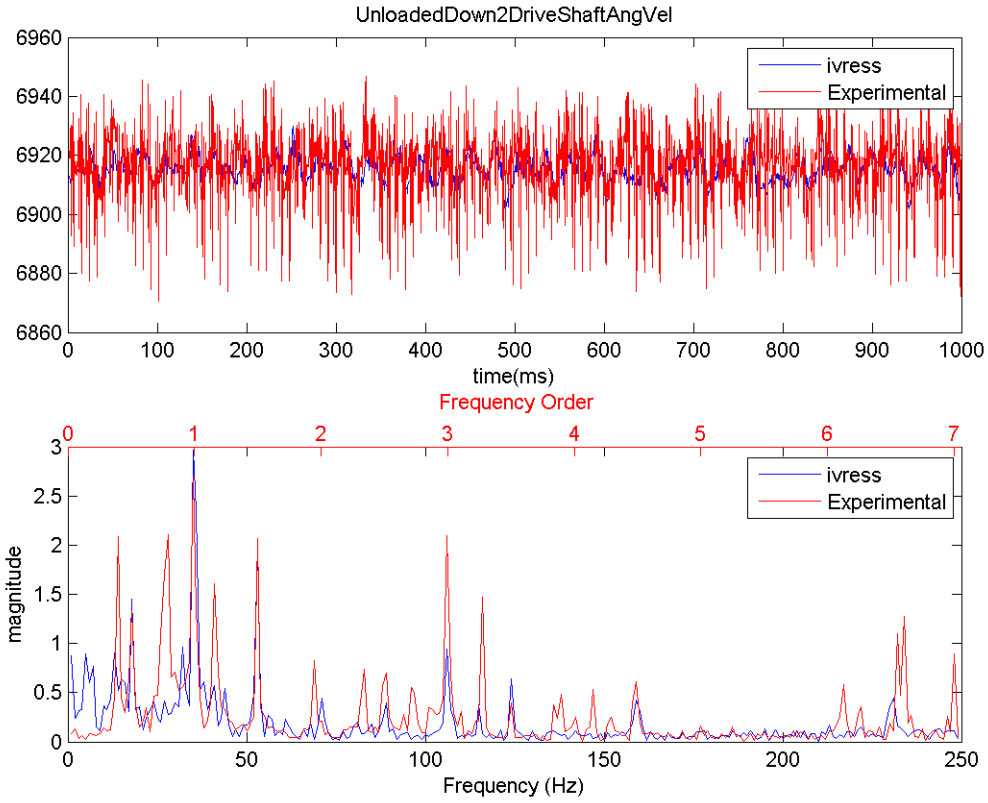

Figure 176 Drive shaft angular velocity in the UnloadedDown operation range with pinion tooth stiffness increased to $4 \times 10^{13} N/m$ instead of $2 \times 10^{13} N/m$ in the baseline

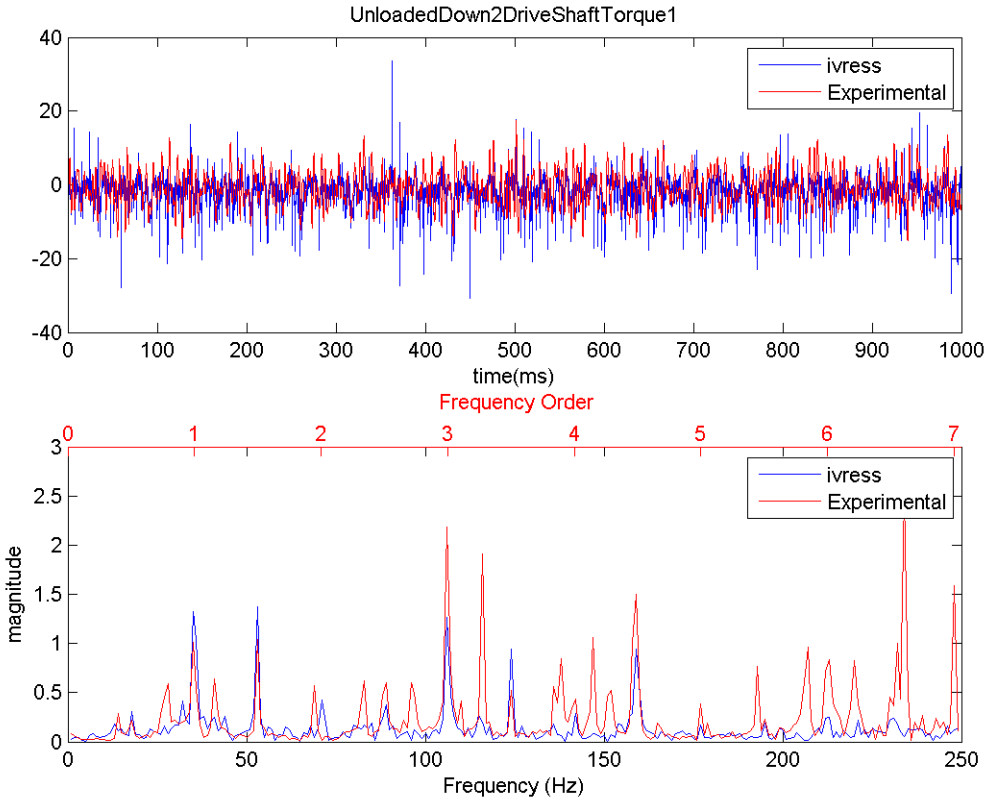

Figure 177 Crankshaft angular velocity in the UnloadedDown operation range with pinion tooth stiffness increased to $4 \times 10^{13} N/m$ instead of $2 \times 10^{13} N/m$ in the baseline

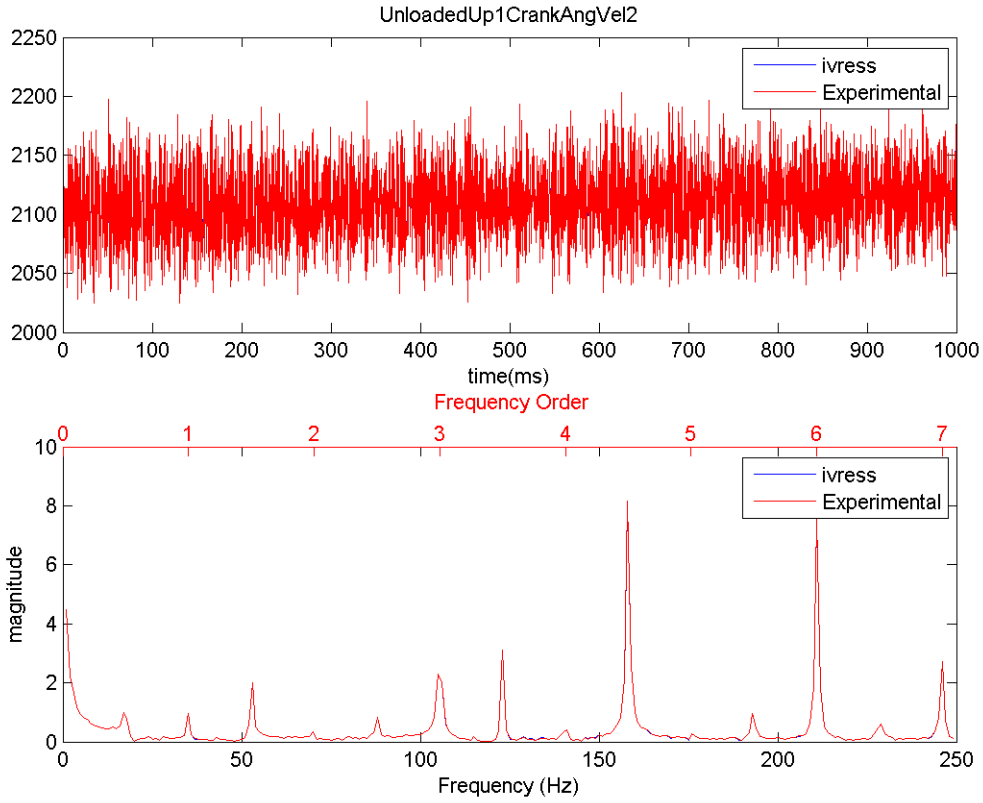

Figure 178 Crankshaft angular velocity in the UnloadedUp operation range with pinion tooth stiffness increased to $4 \times 10^{13} N/m$ instead of $2 \times 10^{13} N/m$ in the baseline

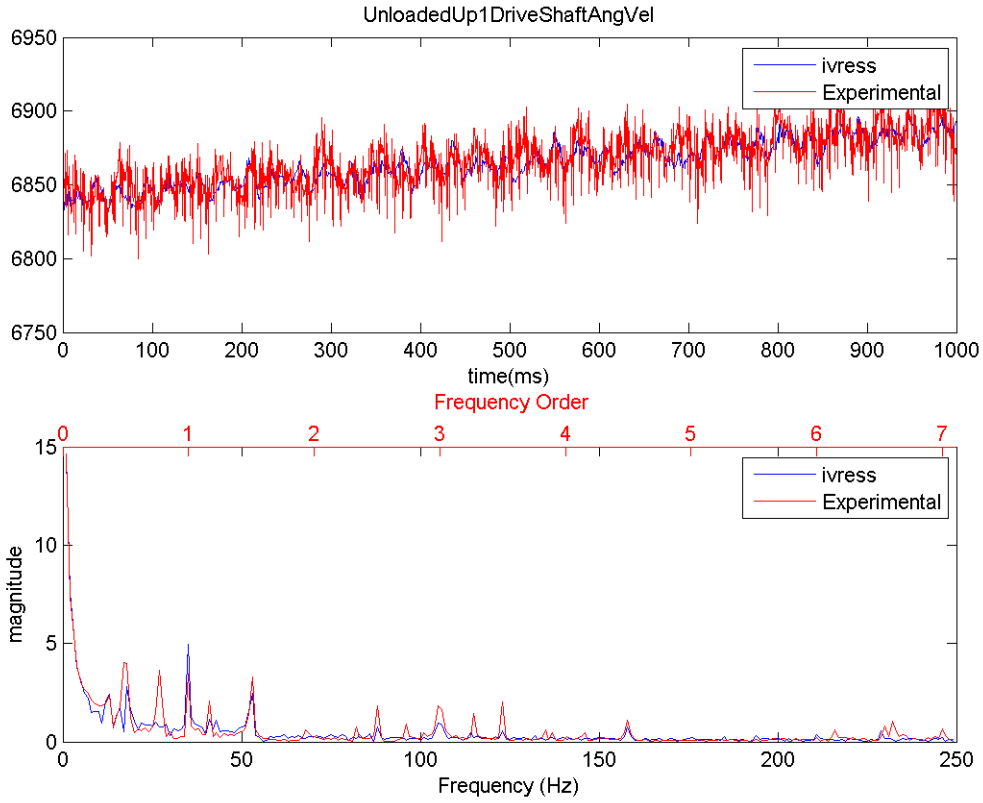

Figure 179 Drive shaft angular velocity in the UnloadedUp operation range with pinion tooth stiffness increased to $4 \times 10^{13} N/m$ instead of $2 \times 10^{13} N/m$ in the baseline

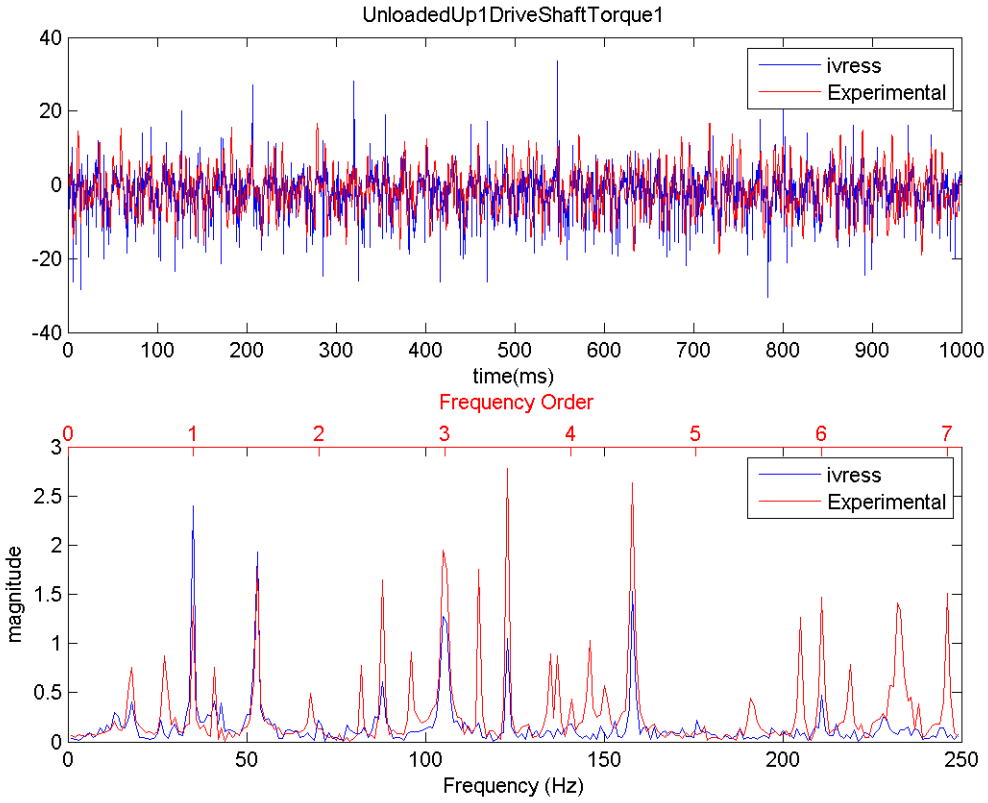

Figure 180 Drive shaft torque in the UnloadedUp operation range with pinion tooth stiffness increased to $4 \times 10^{13} N/m$ instead of $2 \times 10^{13} N/m$ in the baseline

11 Pinion Tooth Damping Decreased To $2 \times 10^6 N.s/m$ Instead Of $4 \times 10^6 N.s/m$ In The Baseline

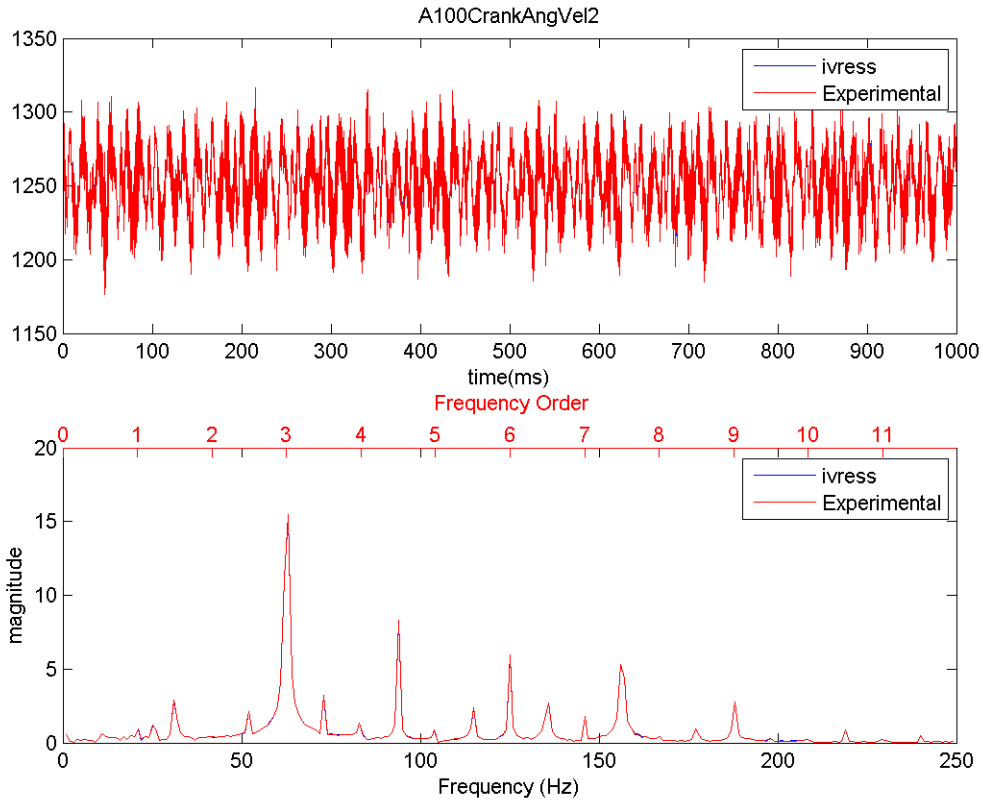

Figure 181 Crankshaft angular velocity in the A100 operation range with pinion tooth damping decreased to $2 \times 10^6 N.s/m$ instead of $4 \times 10^6 N.s/m$ in the baseline

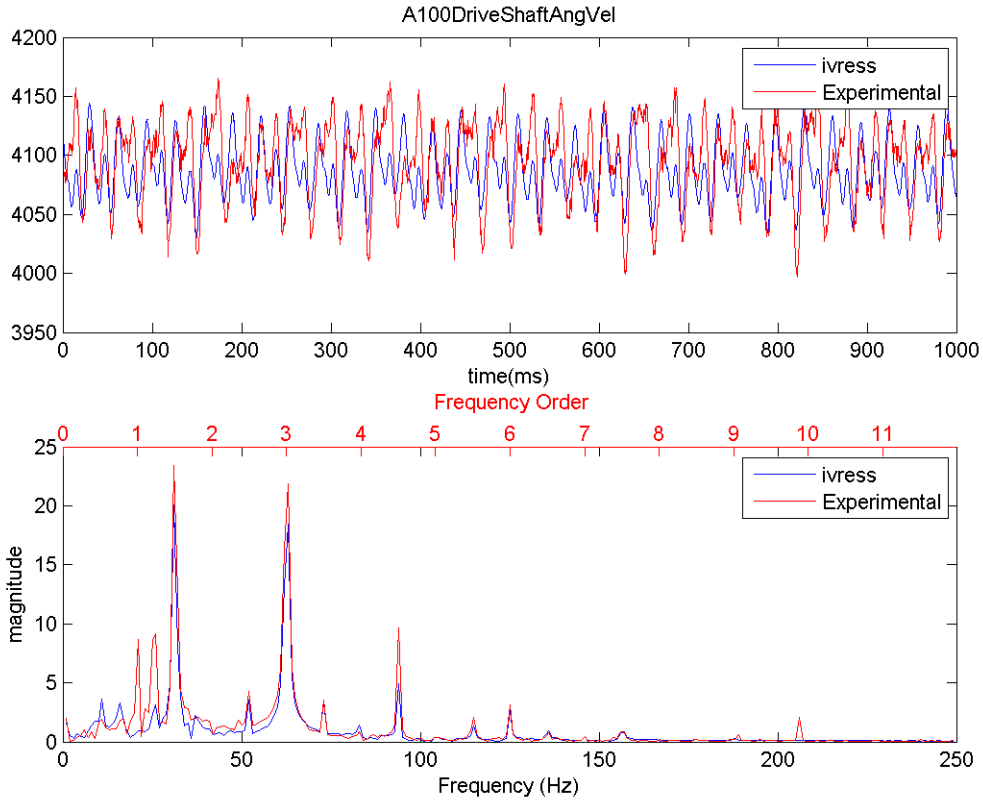

Figure 182 Drive shaft angular velocity in the A100 operation range with pinion tooth damping decreased to $2 \times 10^6 N.s/m$ instead of $4 \times 10^6 N.s/m$ in the baseline

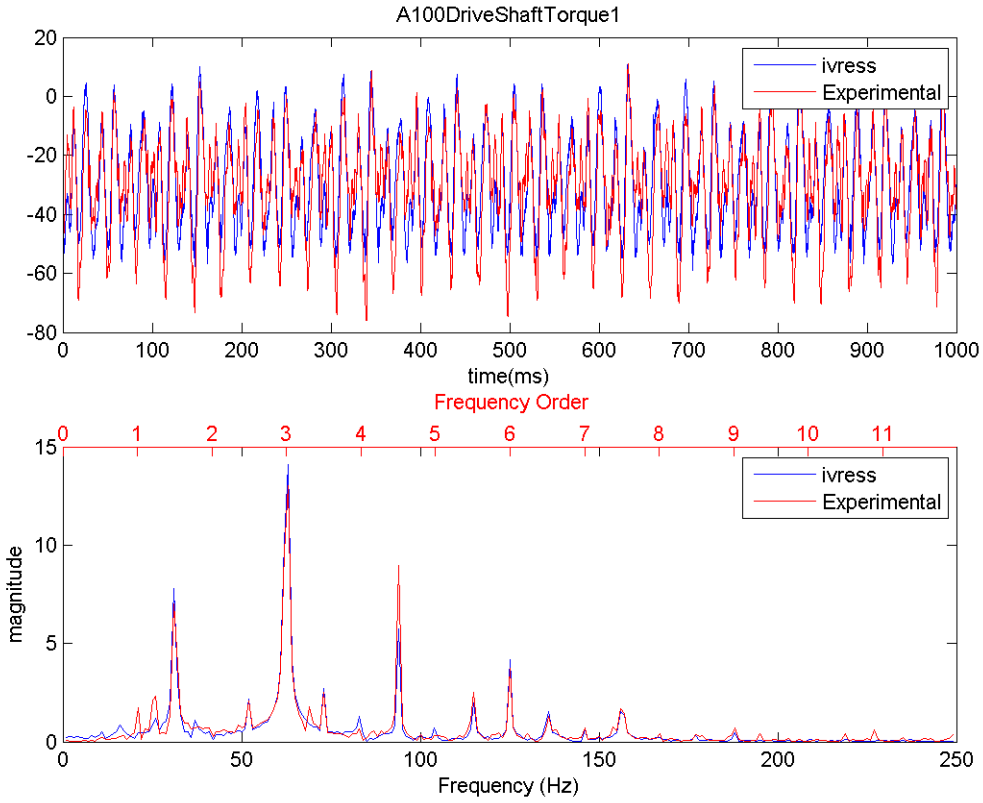

Figure 183 Drive shaft torque in the A100 operation range with pinion tooth damping decreased to $2 \times 10^6 N.s/m$ instead of $4 \times 10^6 N.s/m$ in the baseline

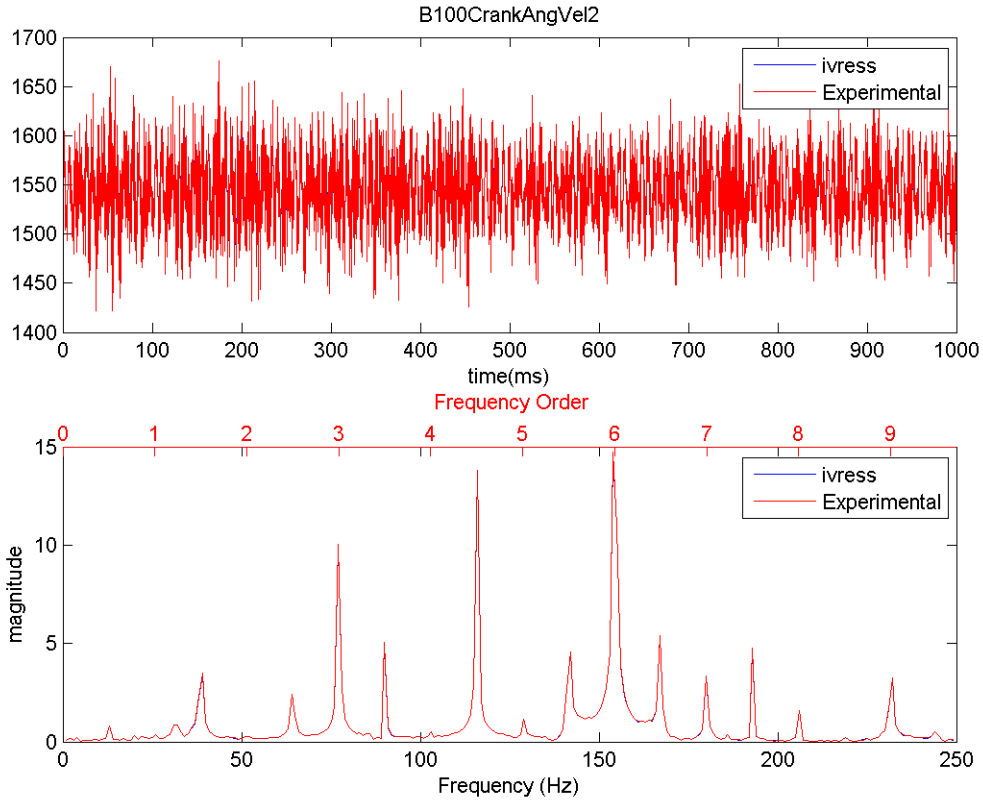

Figure 184 Crankshaft angular velocity in the B100 operation range with pinion tooth damping decreased to $2 \times 10^6 N.s/m$ instead of $4 \times 10^6 N.s/m$ in the baseline

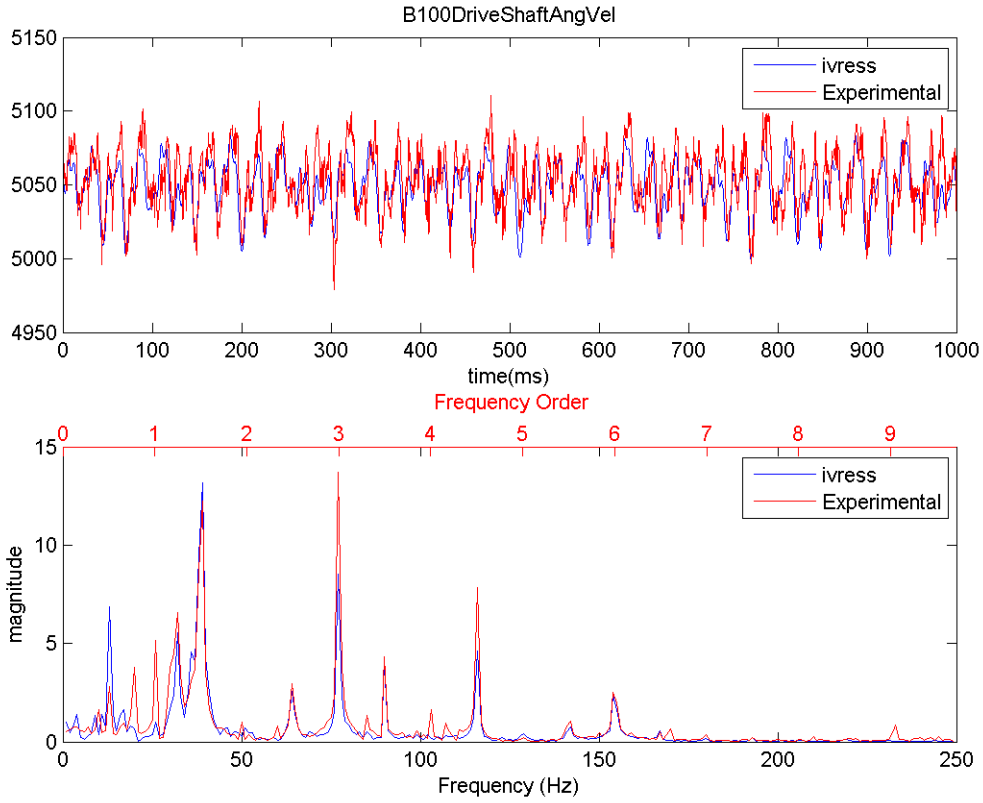

Figure 185 Drive shaft angular velocity in the B100 operation range with pinion tooth damping decreased to $2 \times 10^6 N.s/m$ instead of $4 \times 10^6 N.s/m$ in the baseline

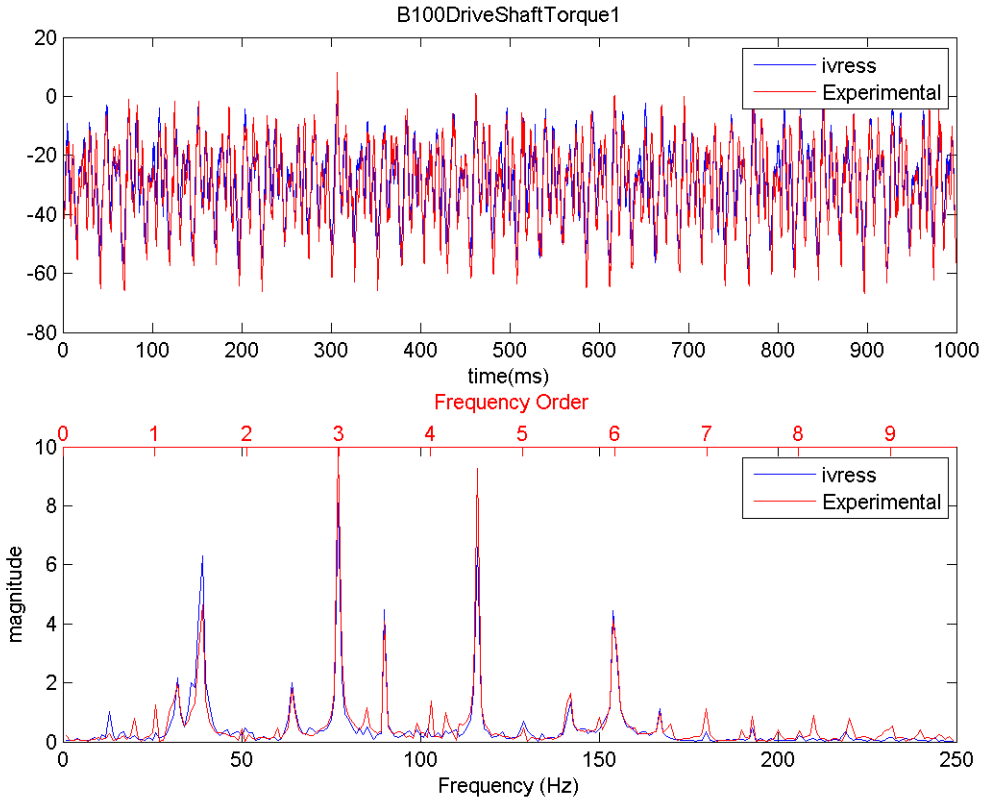

Figure 186 Drive shaft torque in the B100 operation range with pinion tooth damping decreased to $2 \times 10^6 N.s/m$ instead of $4 \times 10^6 N.s/m$ in the baseline

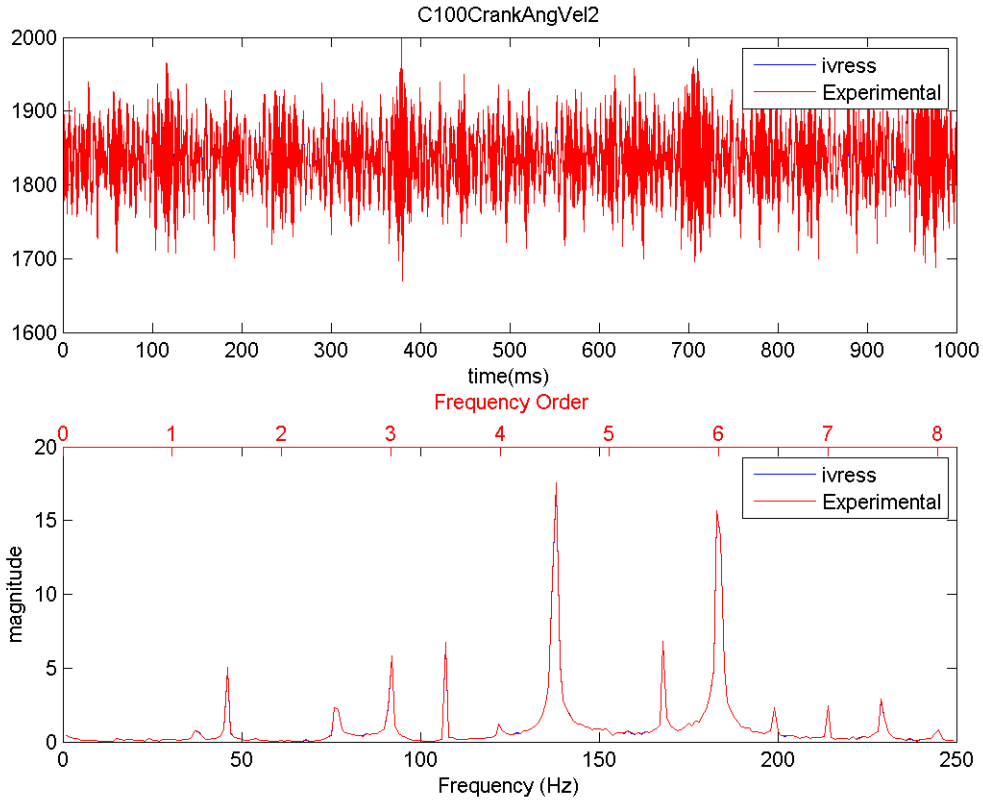

Figure 187 Crankshaft angular velocity in the C100 operation range with pinion tooth damping decreased to $2 \times 10^6 N.s/m$ instead of $4 \times 10^6 N.s/m$ in the baseline

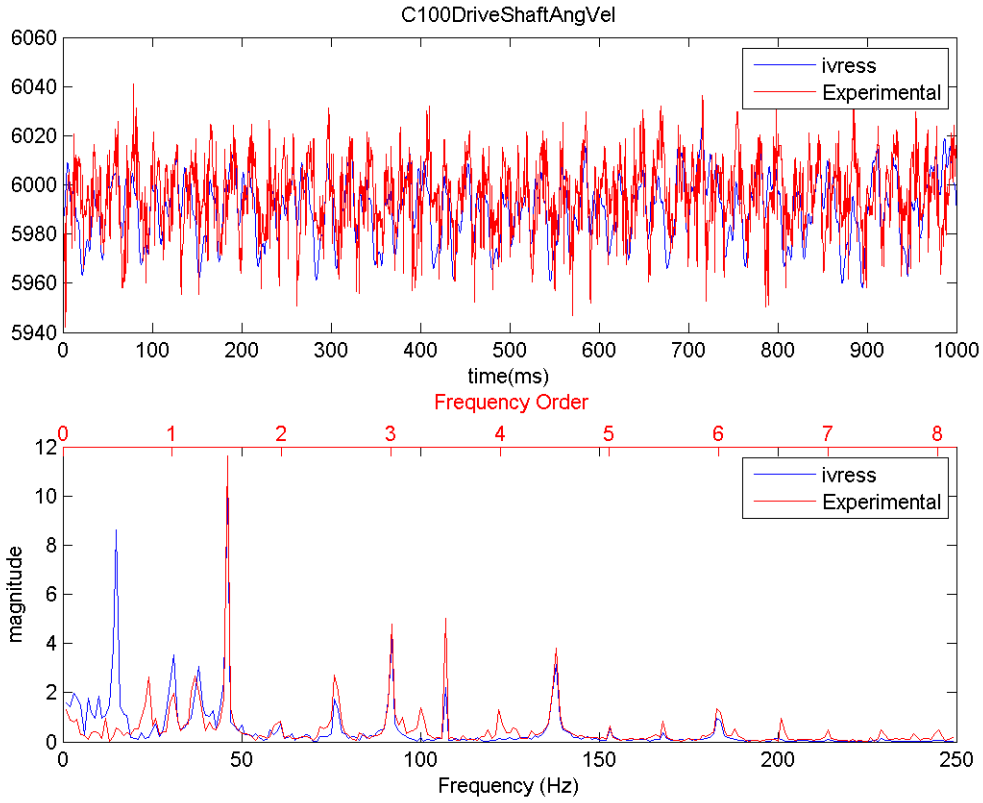

Figure 188 Drive shaft angular velocity in the C100 operation range with pinion tooth damping decreased to $2 \times 10^6 N.s/m$ instead of $4 \times 10^6 N.s/m$ in the baseline

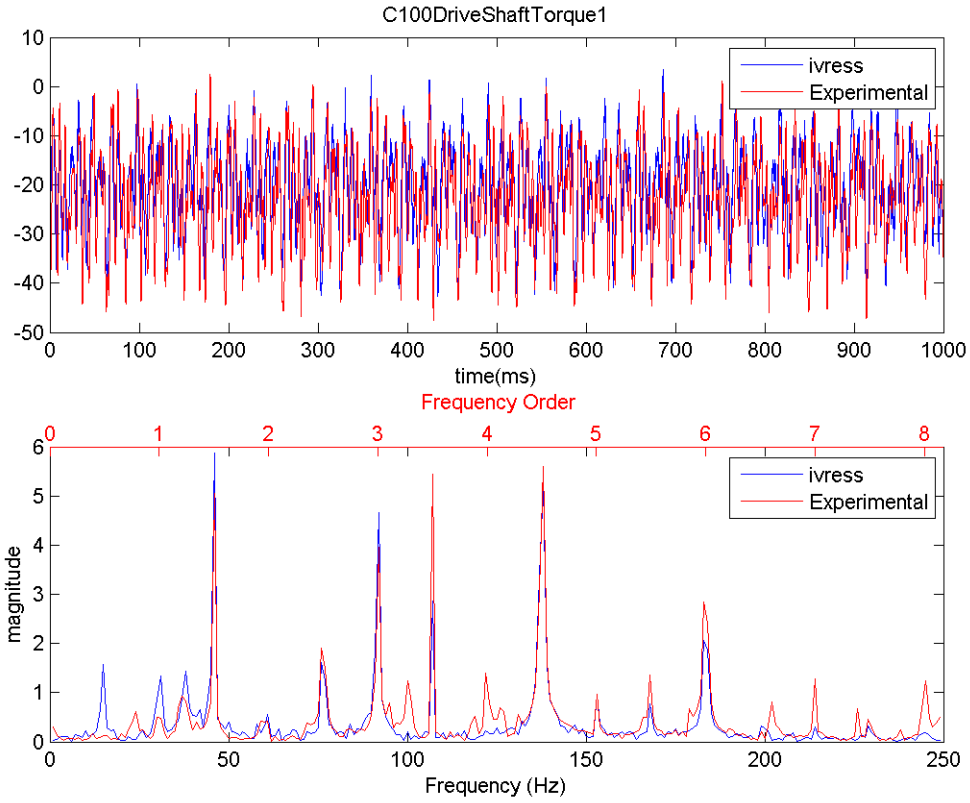

Figure 189 Drive shaft torque in the C100 operation range with pinion tooth damping decreased to $2 \times 10^6 N.s/m$ instead of $4 \times 10^6 N.s/m$ in the baseline

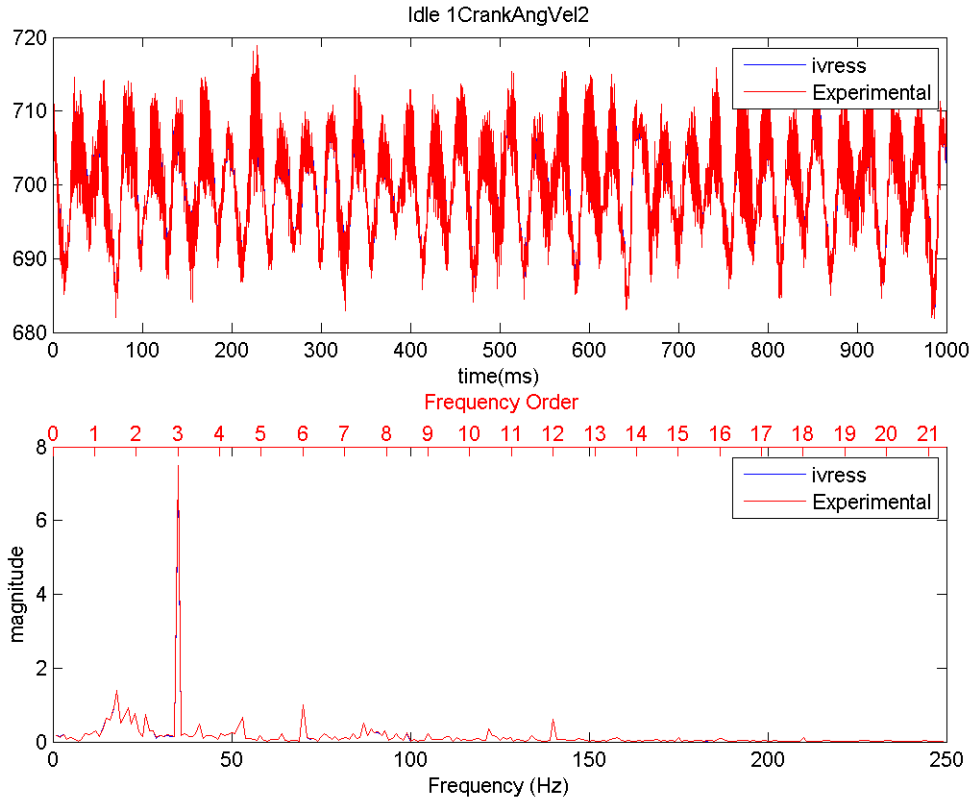

Figure 190 Crankshaft angular velocity in the idle operation range with pinion tooth damping decreased to $2 \times 10^6 N.s/m$ instead of $4 \times 10^6 N.s/m$ in the baseline

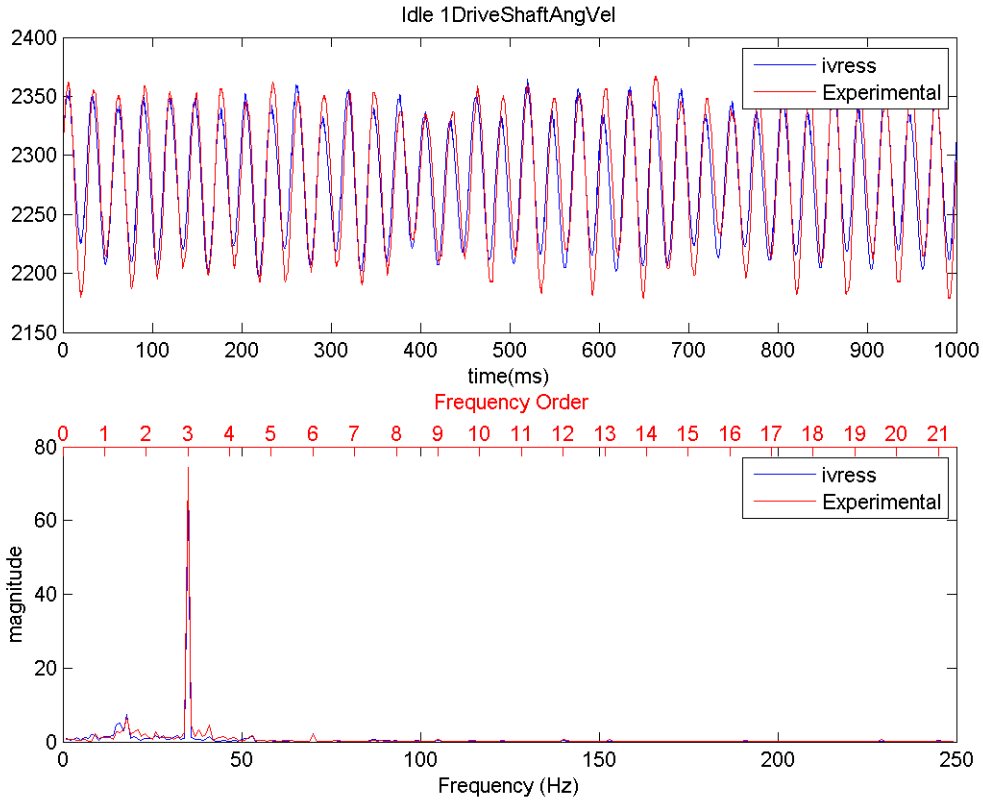

Figure 191 Drive shaft angular velocity in the idle operation range with pinion tooth damping decreased to $2 \times 10^6 N.s/m$ instead of $4 \times 10^6 N.s/m$ in the baseline

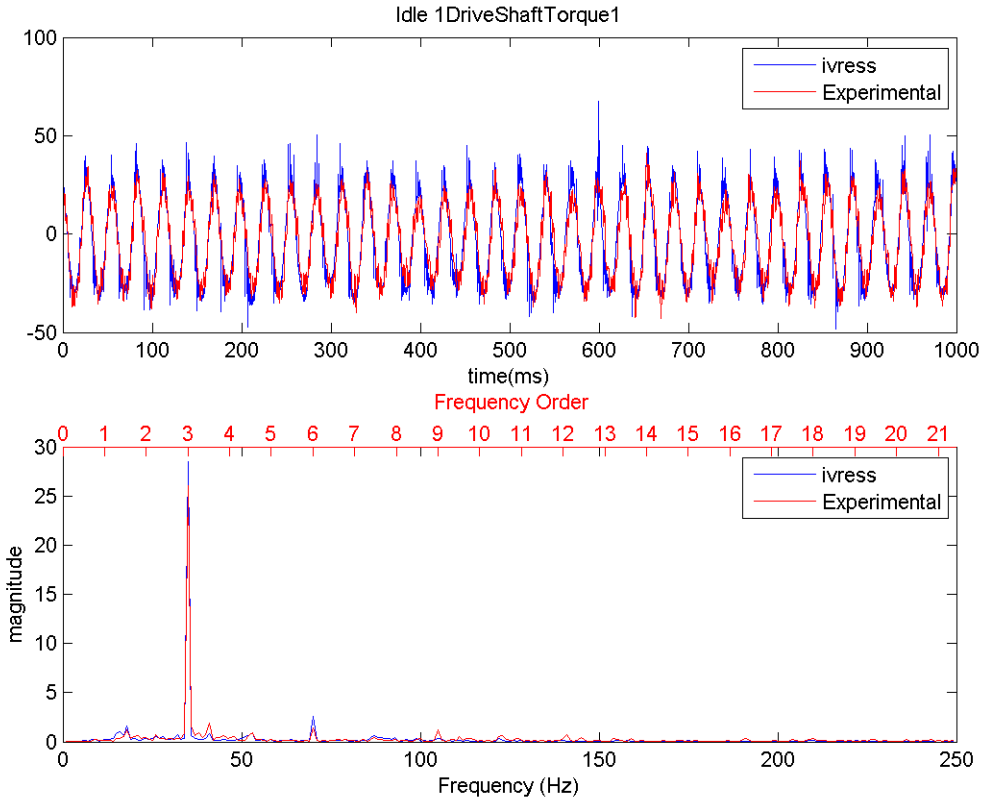

Figure 192 Drive shaft torque in the idle operation range with pinion tooth damping decreased to $2 \times 10^6 N.s/m$ instead of $4 \times 10^6 N.s/m$ in the baseline

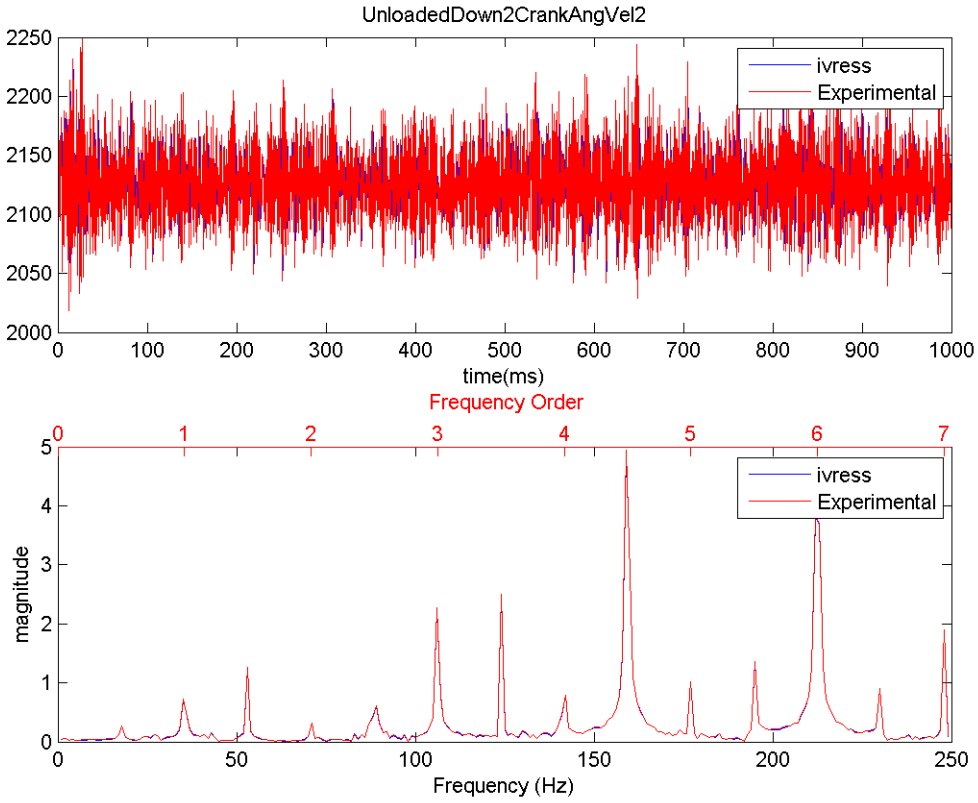

Figure 193 Crankshaft angular velocity in the UnloadedDown operation range with pinion tooth damping decreased to $2 \times 10^6 N.s/m$ instead of $4 \times 10^6 N.s/m$ in the baseline

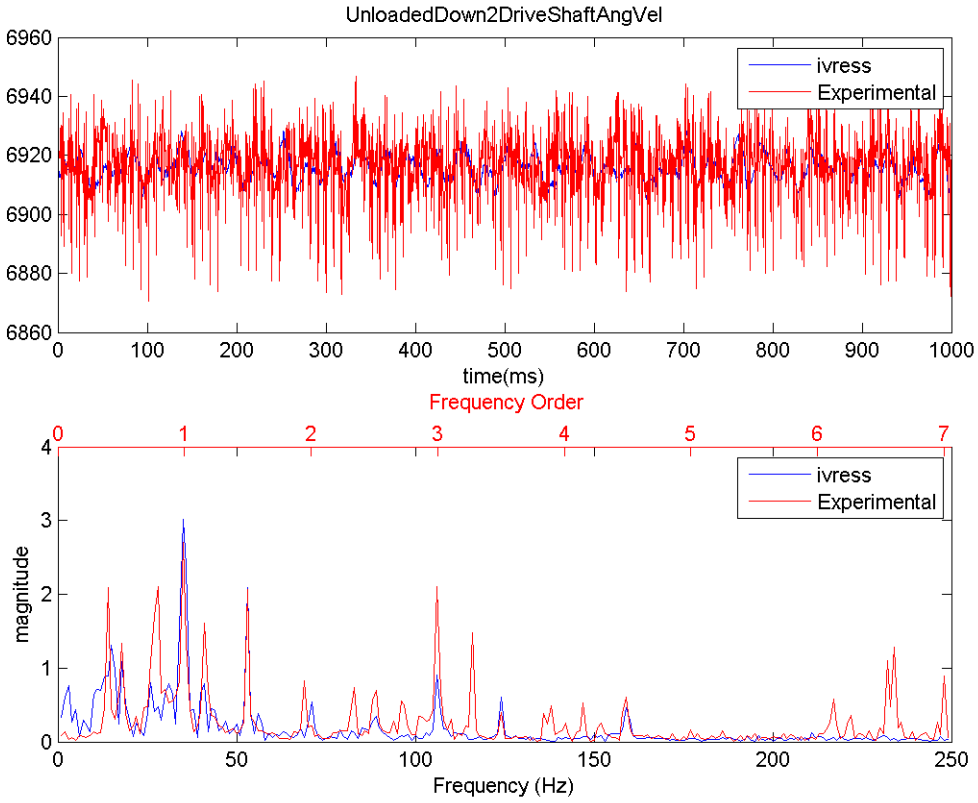

Figure 194 Drive shaft angular velocity in the UnloadedDown operation range with pinion tooth damping decreased to $2 \times 10^6 N.s/m$ instead of $4 \times 10^6 N.s/m$ in the baseline

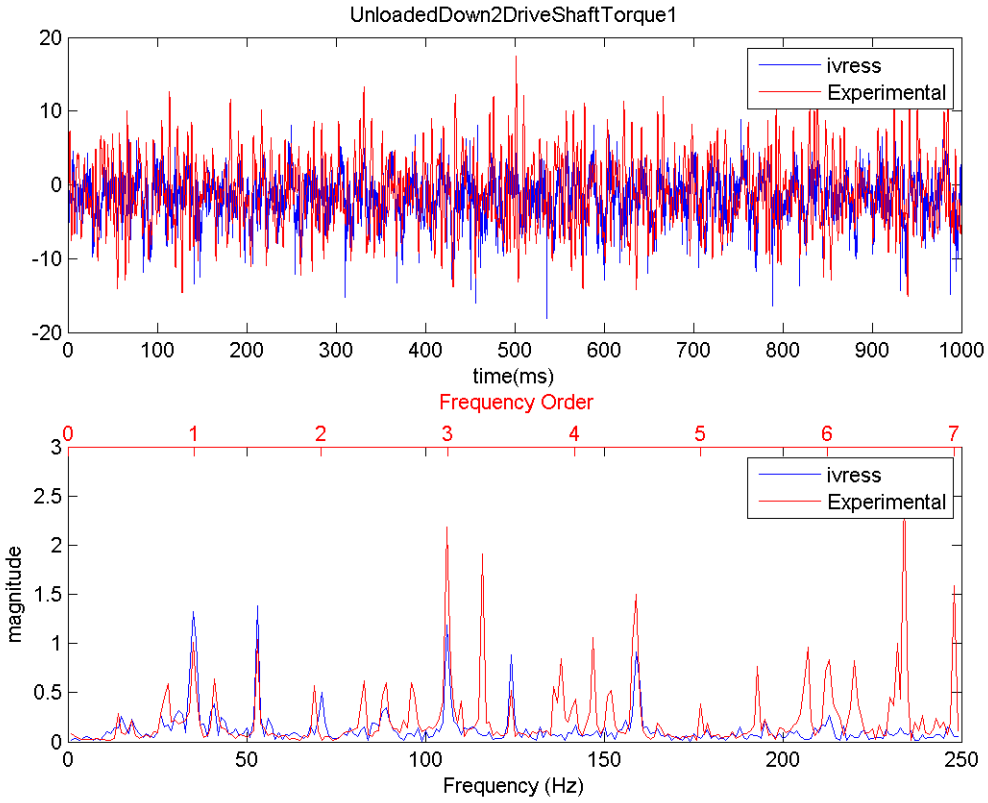

Figure 195 Drive shaft torque in the UnloadedDown operation range with pinion tooth damping decreased to $2 \times 10^6\ N.s/m$ instead of $4 \times 10^6\ N.s/m$ in the baseline

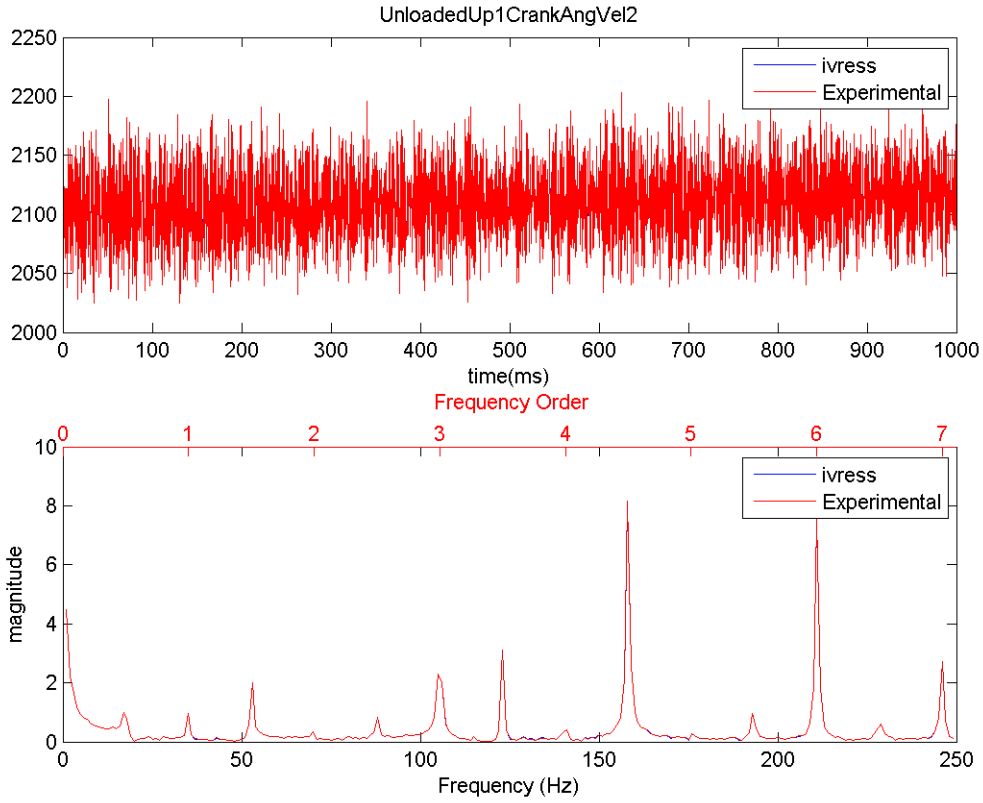

Figure 196 Crankshaft angular velocity in the UnloadedUp operation range with pinion tooth damping decreased to$2 \times 10^6\ N.s/m$ instead of $4 \times 10^6\ N.s/m$ in the baseline

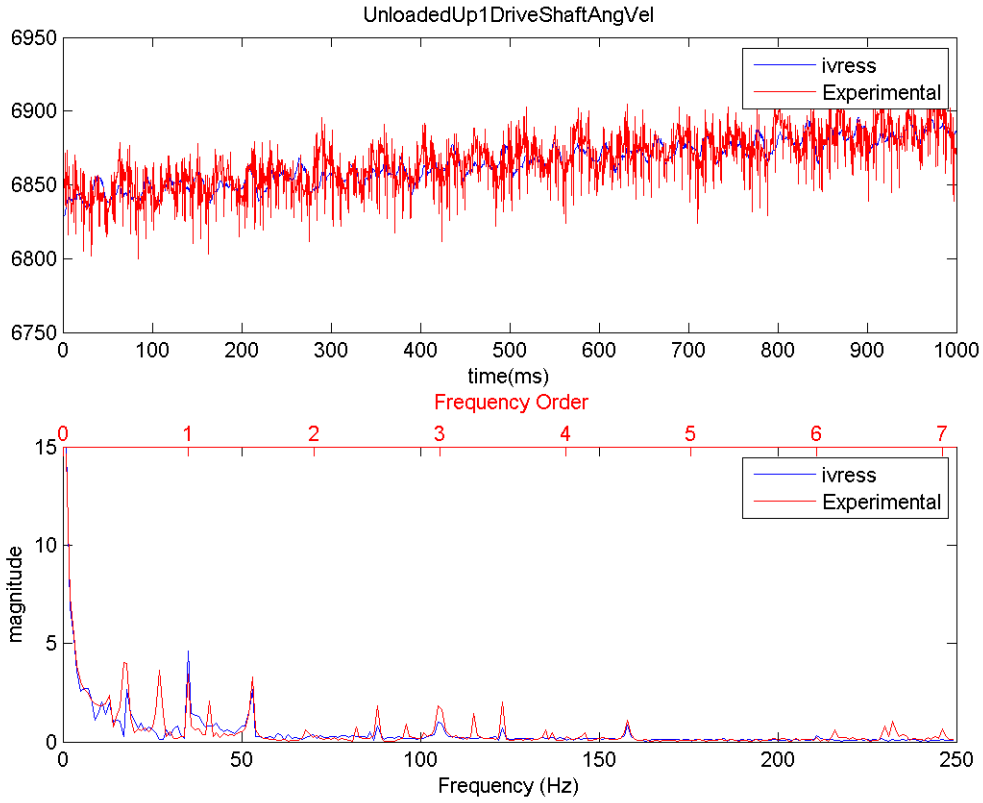

Figure 197 Drive shaft angular velocity in the UnloadedUp operation range with pinion tooth damping decreased to $2 \times 10^6\ N.s/m$ instead of $4 \times 10^6\ N.s/m$ in the baseline

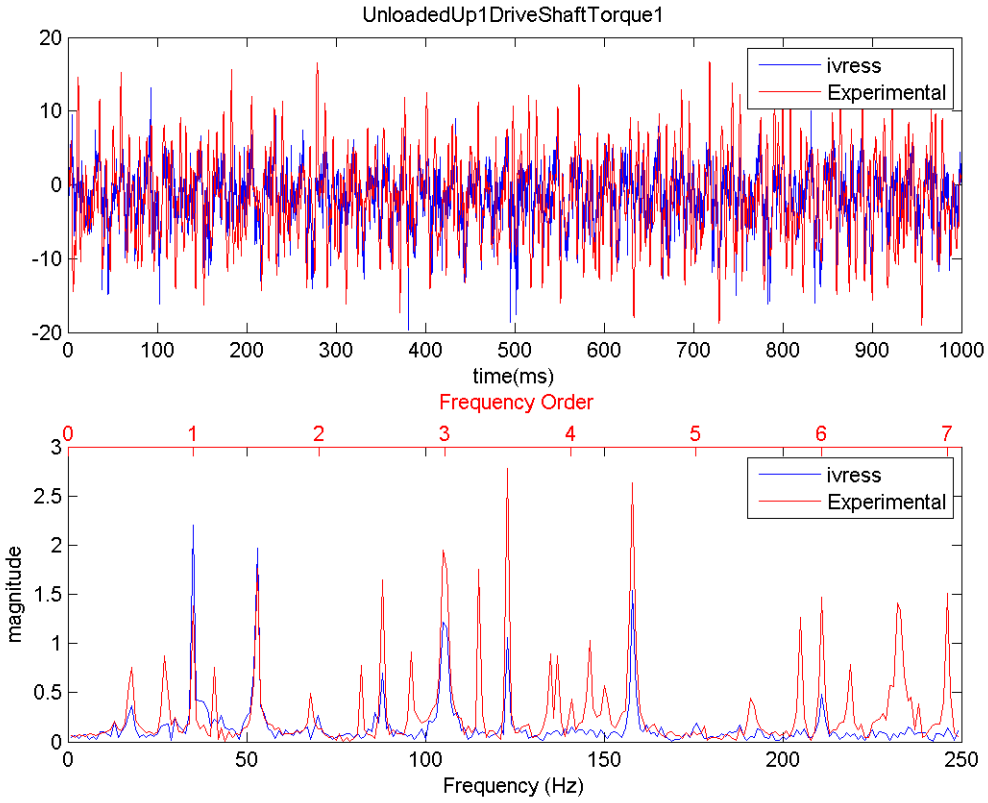

Figure 198 Drive shaft torque in the UnloadedUp operation range with pinion tooth damping decreased to $2 \times 10^6\ N.s/m$ instead of $4 \times 10^6\ N.s/m$ in the baseline

12 Drive Shaft Torsional Stiffness Increased To 7500 Nm/rad Instead Of 5674 Nm/rad

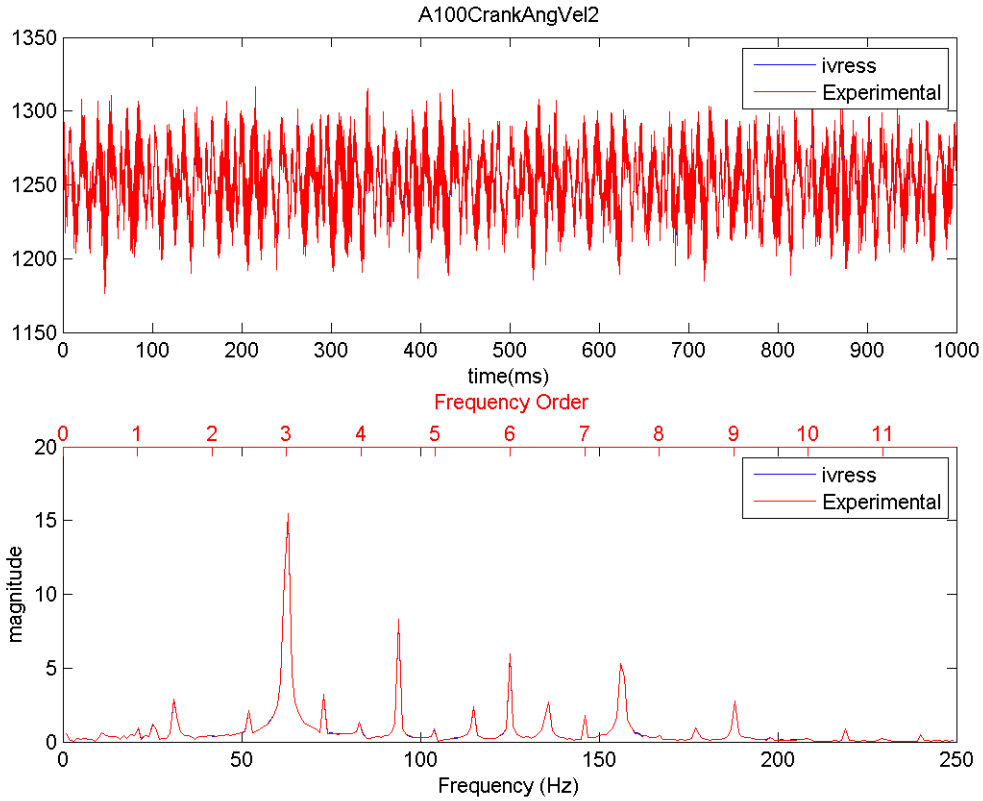

Figure 199 Crankshaft angular velocity in the A100 operation range with drive shaft torsional stiffness increased to 7500 Nm/rad instead of 5674 Nm/rad

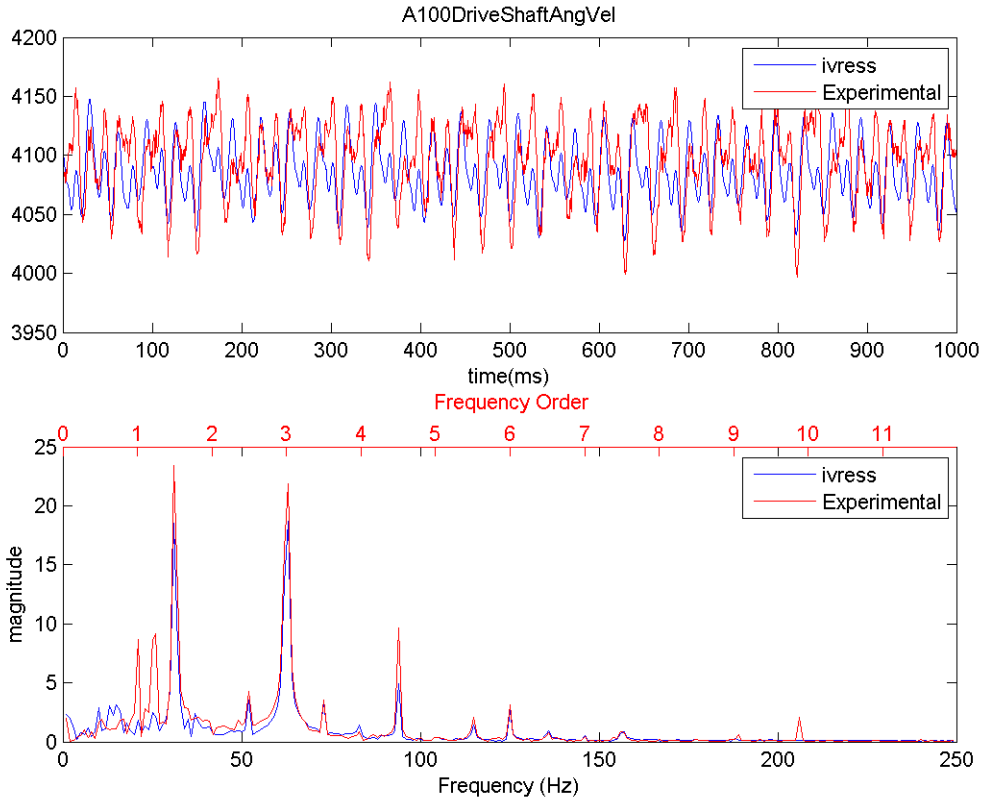

Figure 200 Drive shaft angular velocity in the A100 operation range with drive shaft torsional stiffness increased to 7500 Nm/rad instead of 5674 mN/rad

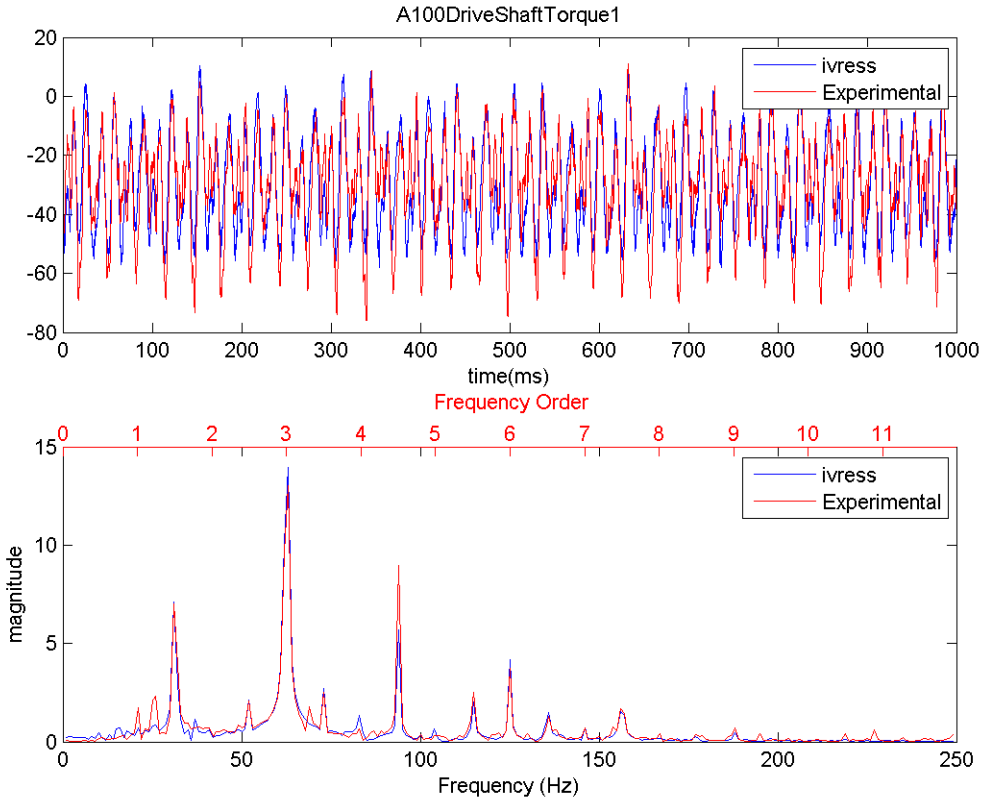

Figure 201 Drive shaft torque in the A100 operation range with drive shaft torsional stiffness increased to 7500 Nm/rad instead of 5674 Nm/rad

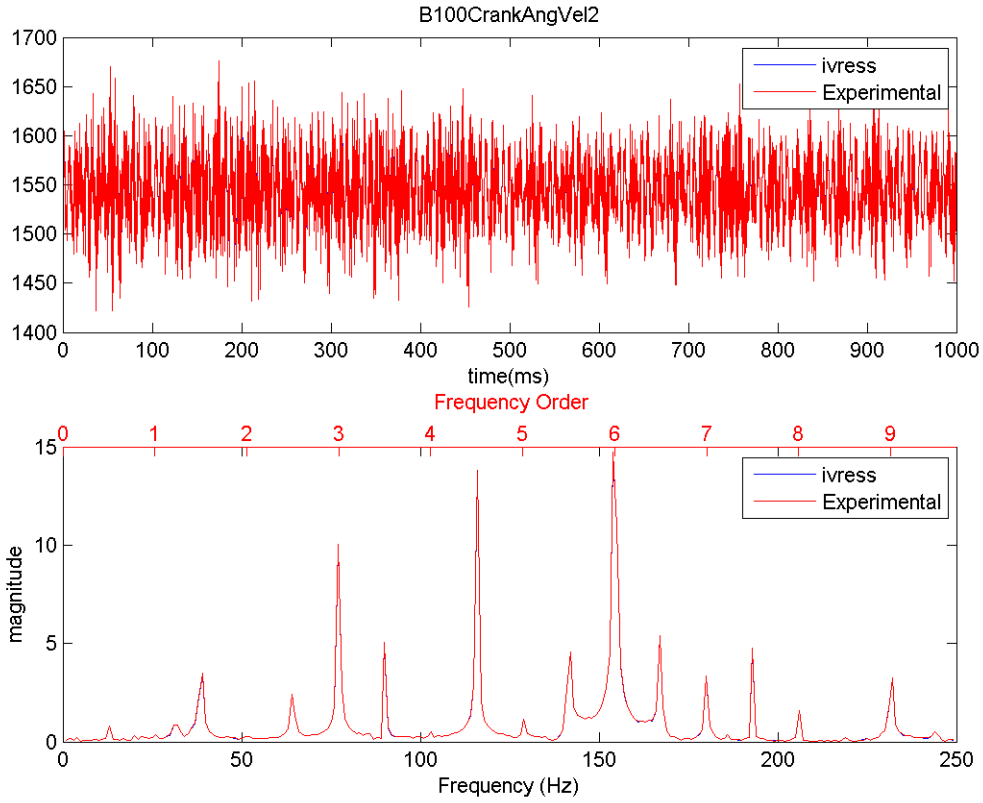

Figure 202 Crankshaft angular velocity in the B100 operation range with drive shaft torsional stiffness increased to 7500 Nm/rad instead of 5674 Nm/rad

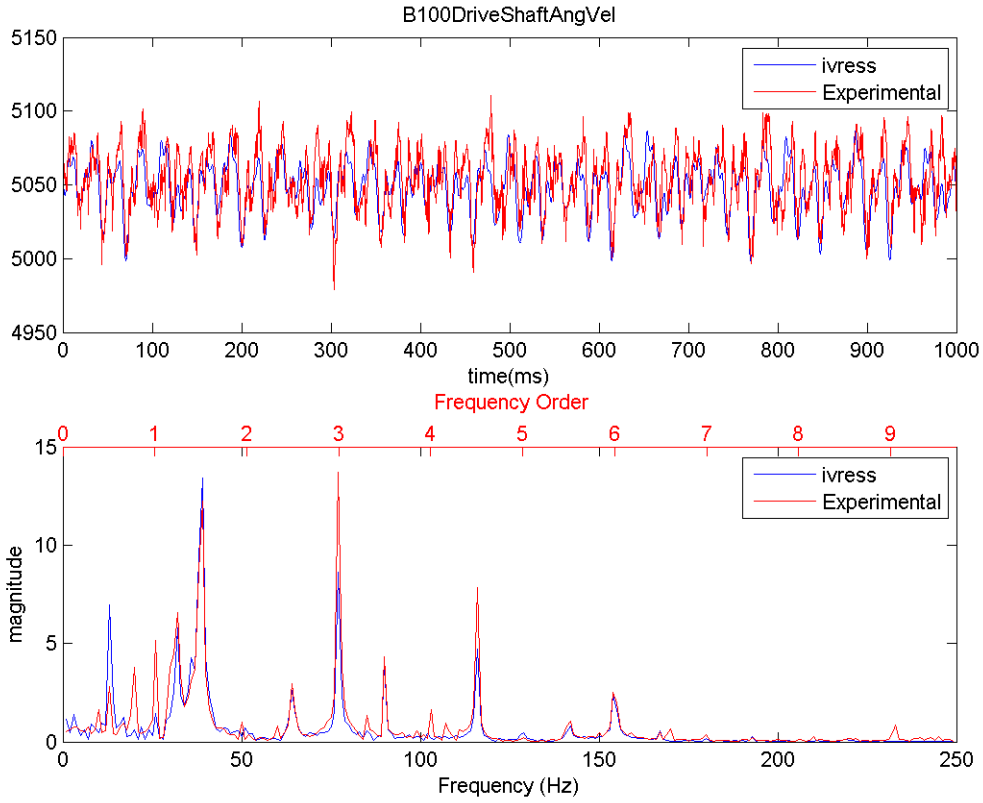

Figure 203 Drive shaft angular velocity in the B100 operation range with drive shaft torsional stiffness increased to 7500 Nm/rad instead of 5674 Nm/rad

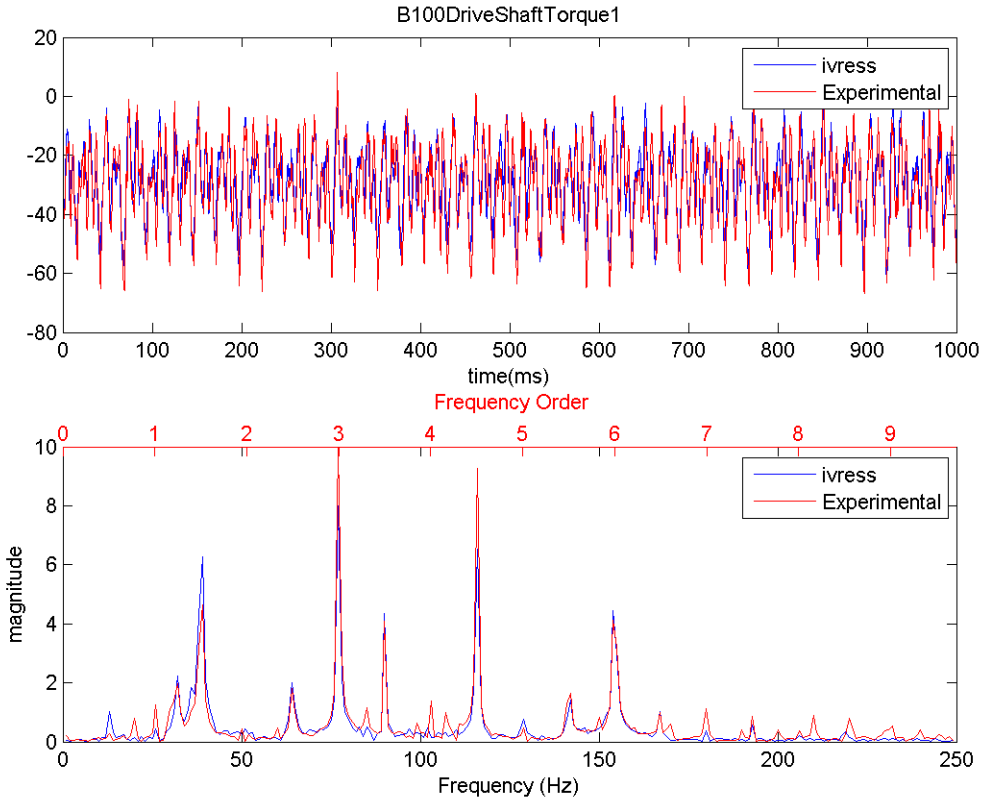

Figure 204 Drive shaft torque in the B100 operation range with drive shaft torsional stiffness increased to 7500 Nm/rad instead of 5674 Nm/rad

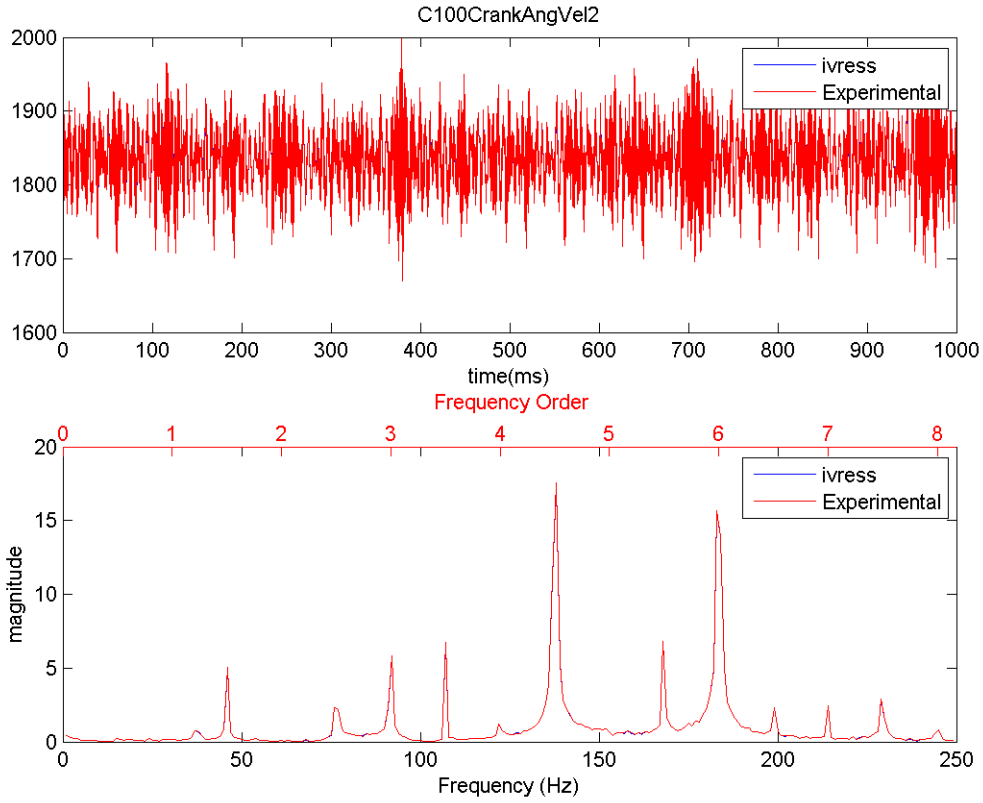

Figure 205 Crankshaft angular velocity in the C100 operation range with drive shaft torsional stiffness increased to 7500 Nm/rad instead of 5674 Nm/rad

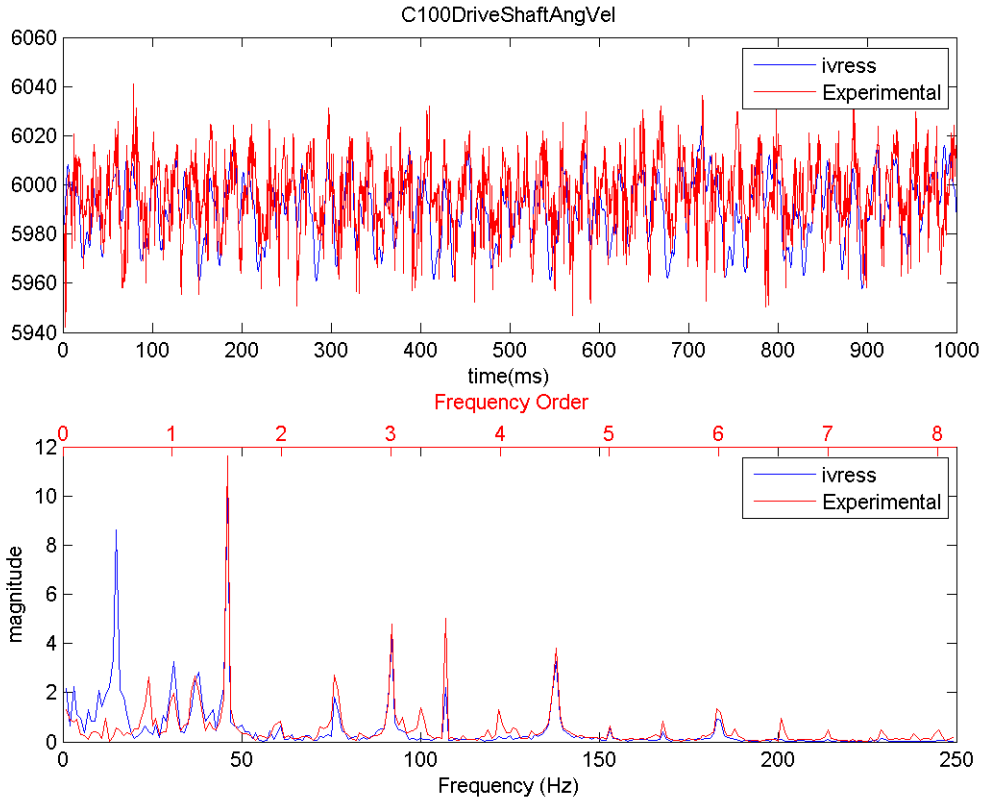

Figure 206 Drive shaft angular velocity in the C100 operation range with drive shaft torsional stiffness increased to 7500 Nm/rad instead of 5674 Nm/rad

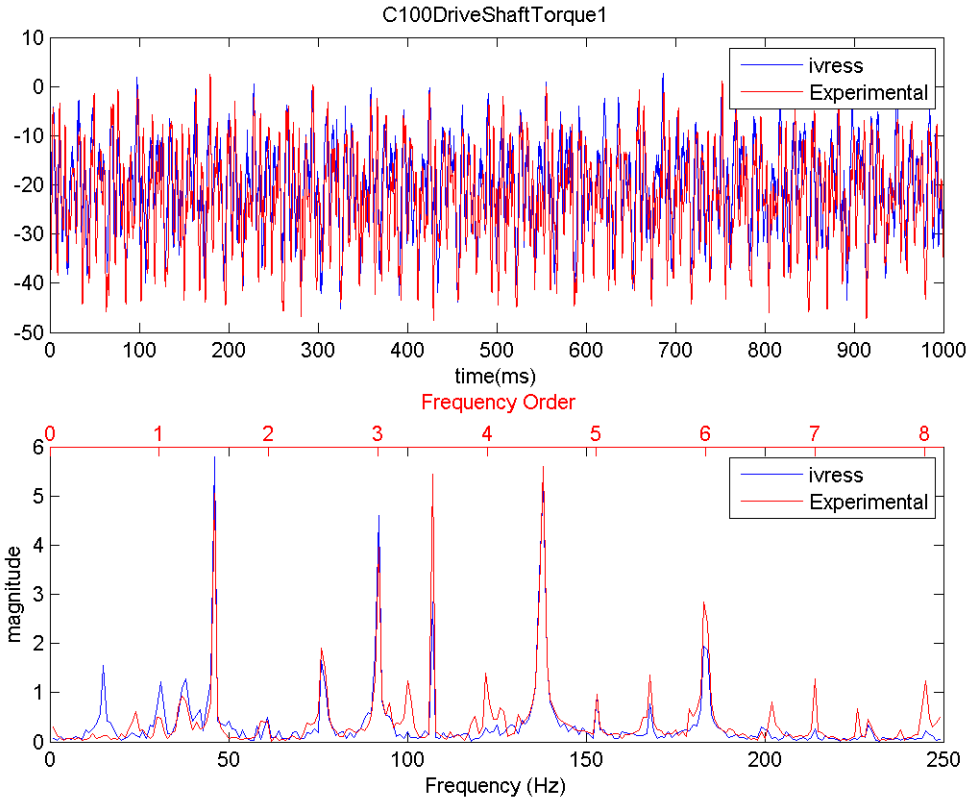

Figure 207 Drive shaft torque in the C100 operation range with drive shaft torsional stiffness increased to 7500 Nm/rad instead of 5674 Nm/rad

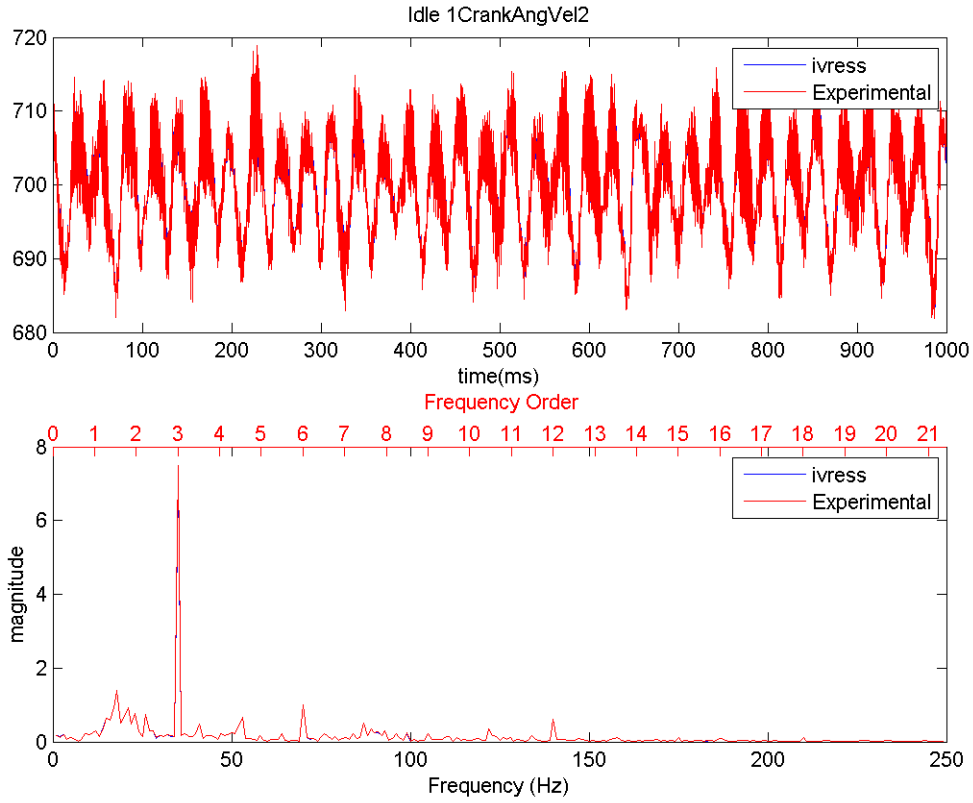

Figure 208 Crankshaft angular velocity in the idle operation range with drive shaft torsional stiffness increased to 7500 Nm/rad instead of 5674 Nm/rad

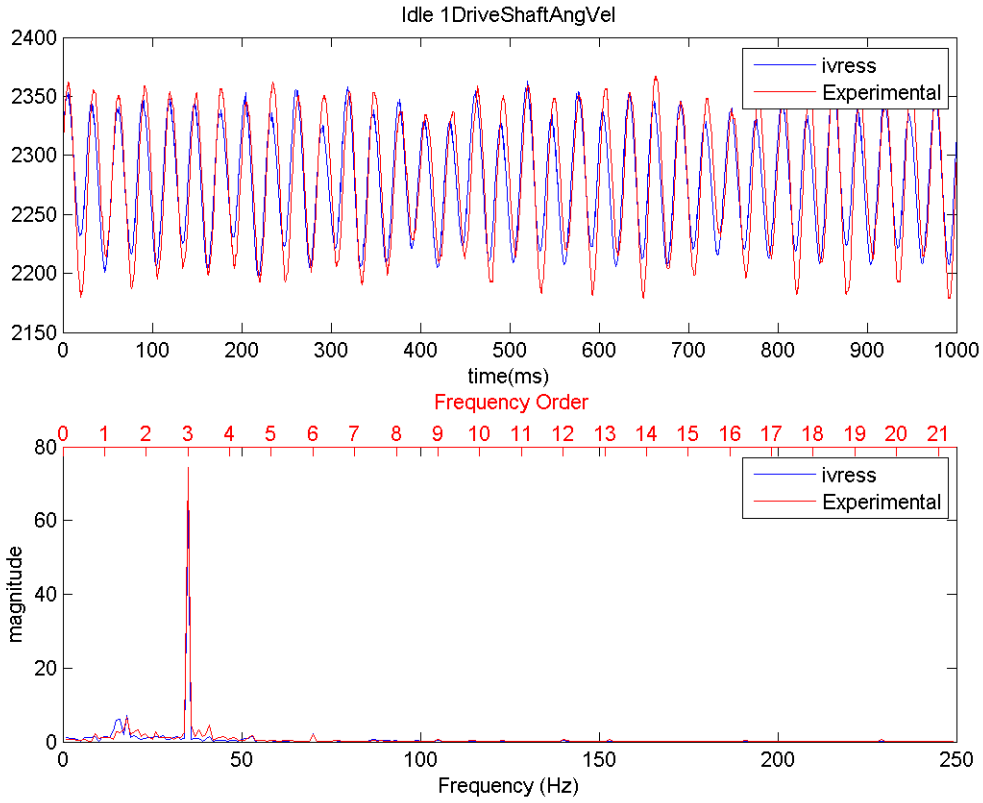

Figure 209 Drive shaft angular velocity in the idle operation range with drive shaft torsional stiffness increased to 7500 Nm/rad instead of 5674 Nm/rad

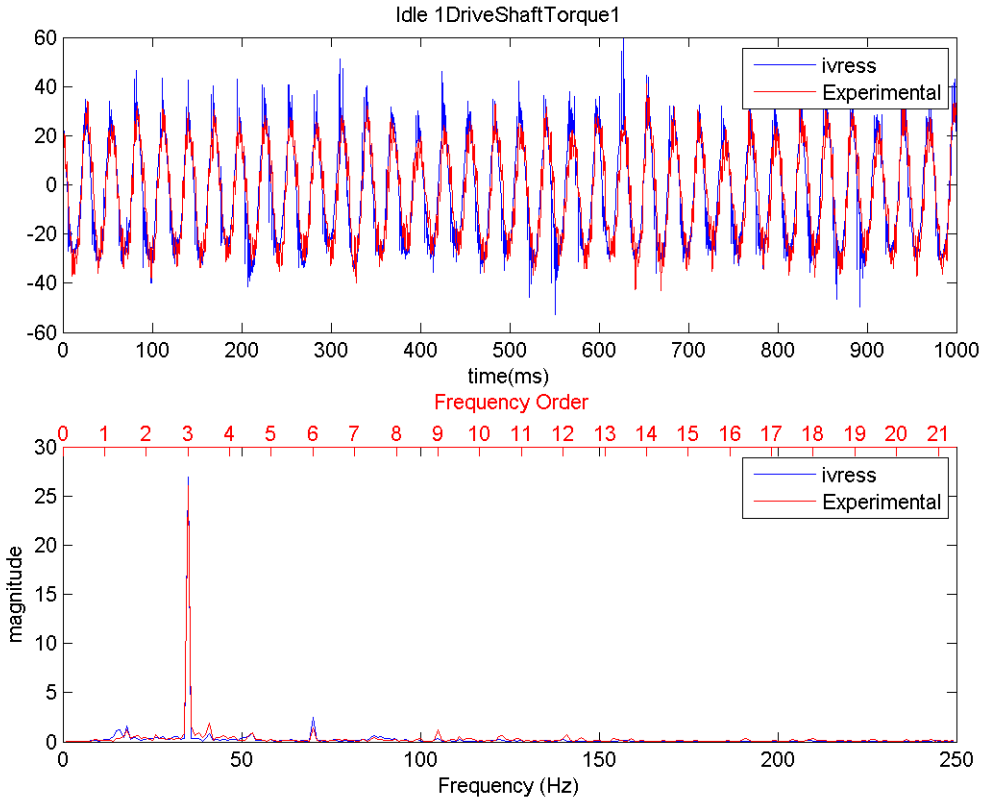

Figure 210 Drive shaft torque in the idle operation range with drive shaft torsional stiffness increased to 7500 Nm/rad instead of 5674 Nm/rad

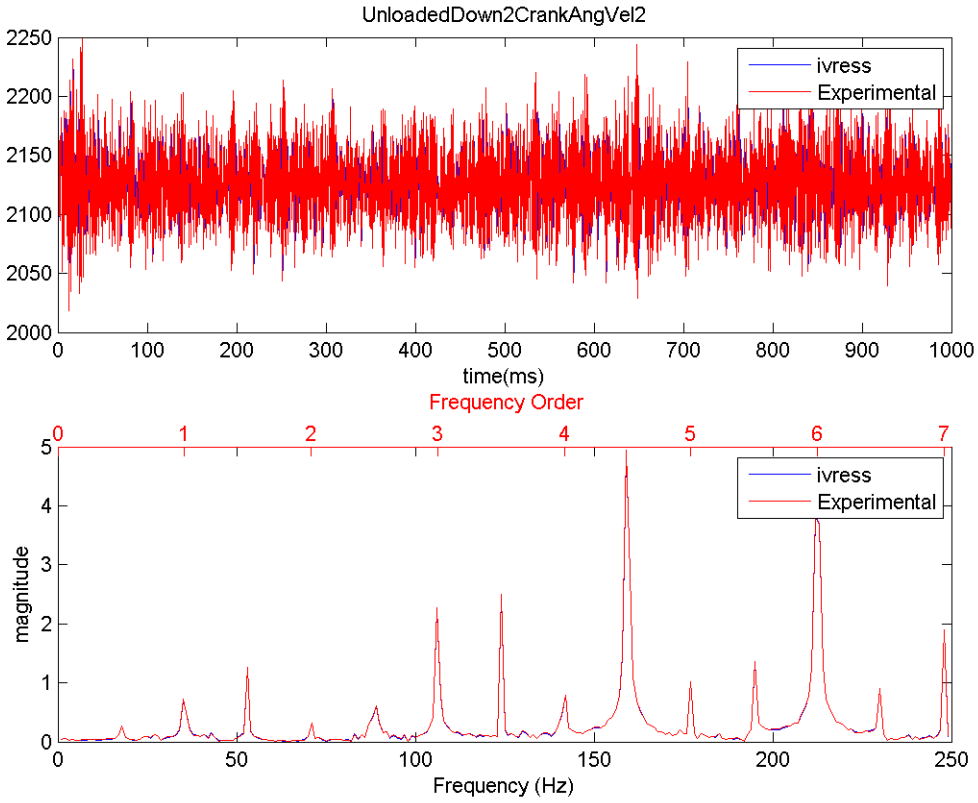

Figure 211 Crankshaft angular velocity in the UnloadedDown operation range with drive shaft torsional stiffness increased to 7500 Nm/rad instead of 5674 Nm/rad

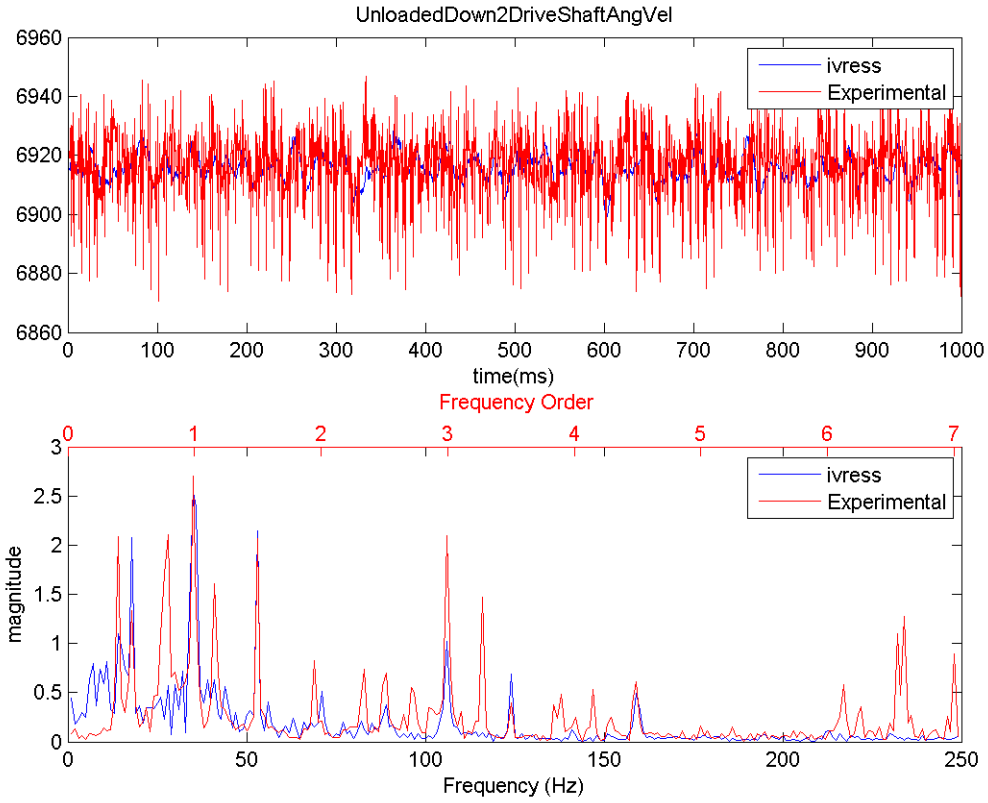

Figure 212 Drive shaft angular velocity in the UnloadedDown operation range with drive shaft torsional stiffness increased to 7500 Nm/rad instead of 5674 Nm/rad

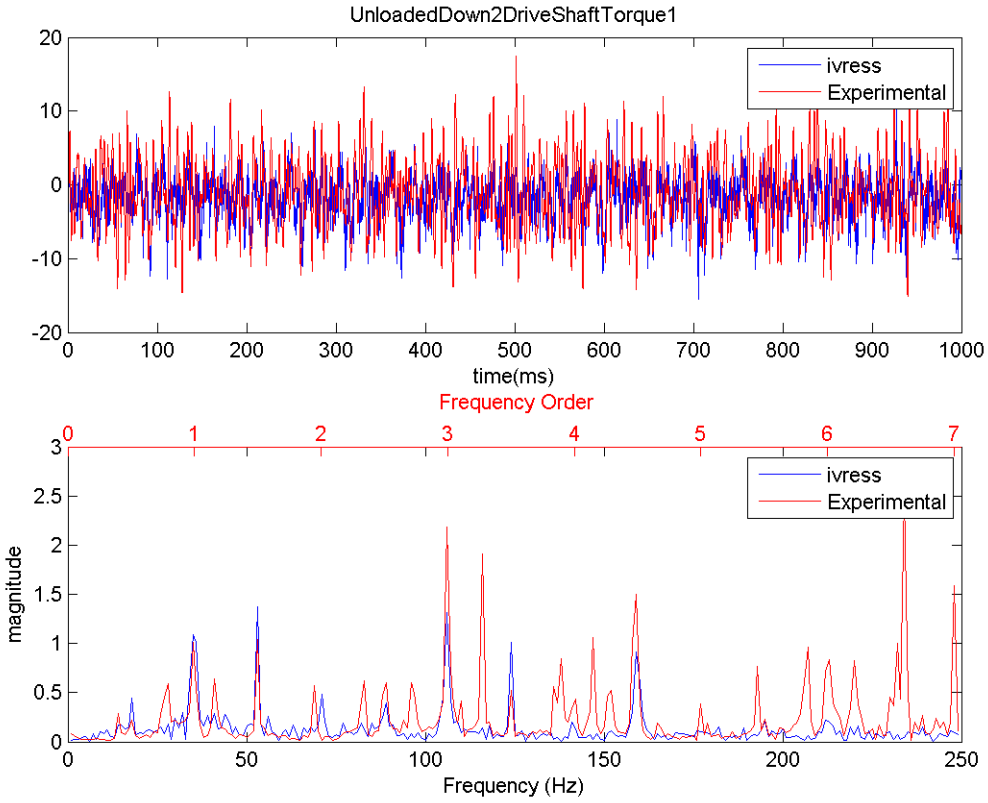

Figure 213 Drive shaft torque in the UnloadedDown operation range with drive shaft torsional stiffness increased to 7500 Nm/rad instead of 5674 Nm/rad

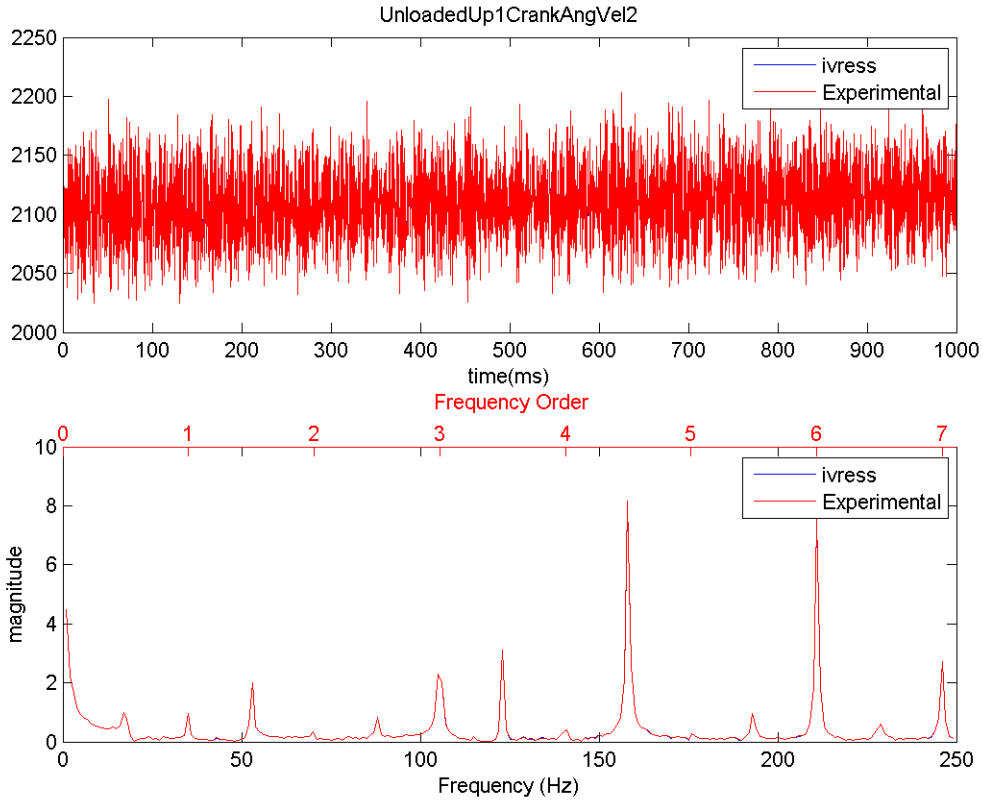

Figure 214 Crankshaft angular velocity in the UnloadedUp operation range with drive shaft torsional stiffness increased to 7500 Nm/rad instead of 5674 Nm/rad

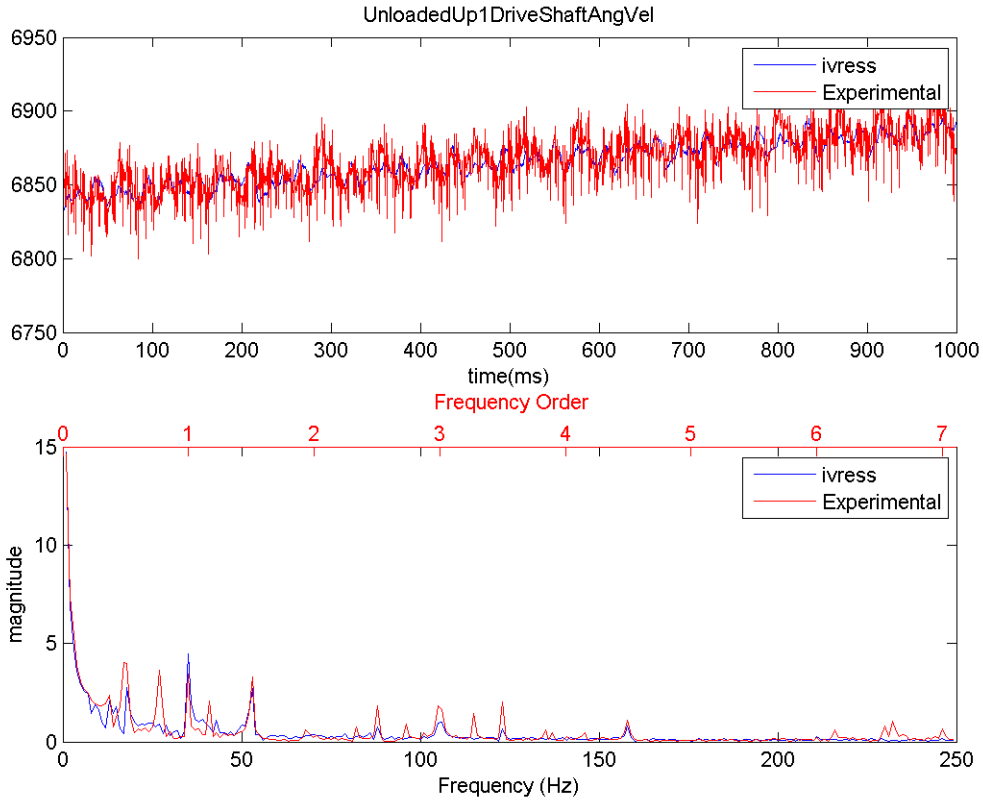

Figure 215 Drive shaft angular velocity in the UnloadedUp operation range with drive shaft torsional stiffness increased to 7500 Nm/rad instead of 5674 Nm/rad

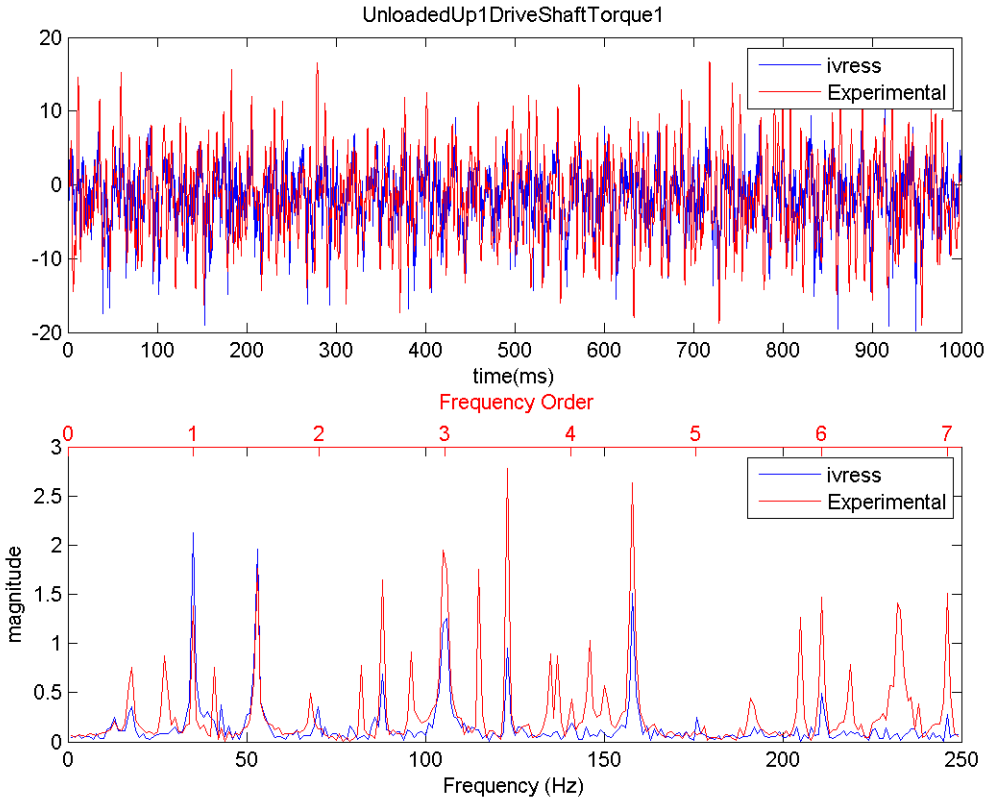

Figure 216 Drive shaft torque in the UnloadedUp operation range with drive shaft torsional stiffness increased to 7500 Nm/rad instead of 5674 Nm/rad

13 Drive Shaft Damping Decreased To $35\ N.m.s/rad$ Instead Of $45\ N.s/rad$ In The Baseline

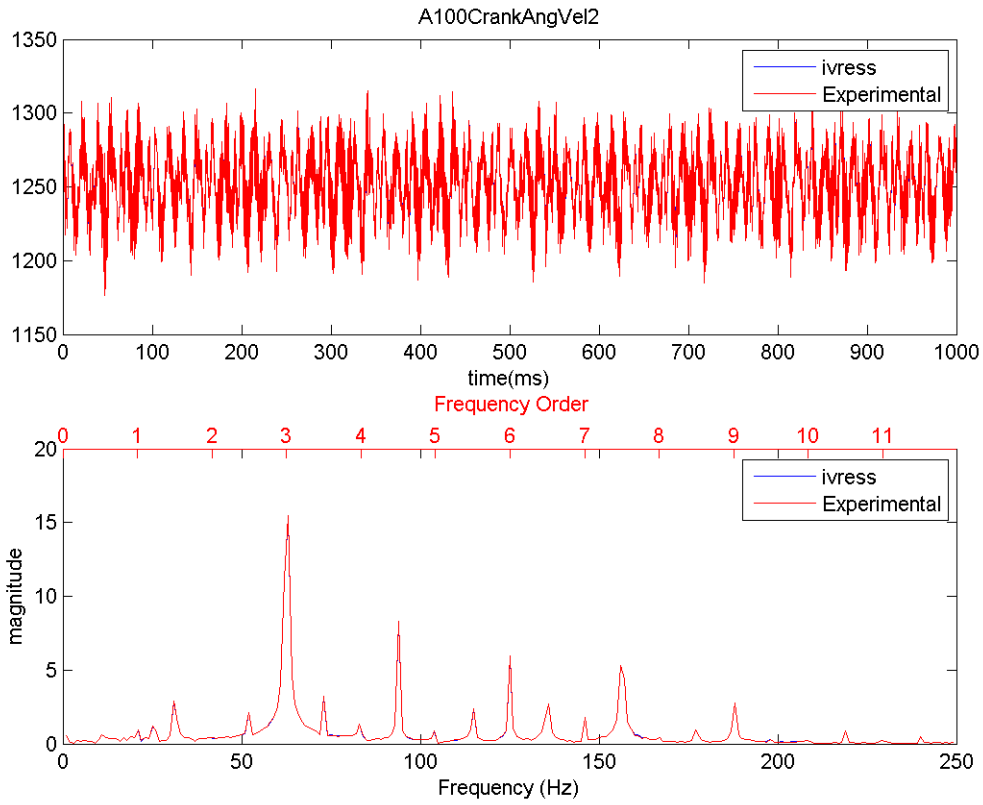

Figure 217 Crankshaft angular velocity in the A100 operation range with drive shaft damping decreased to $35N.m.s/rad$ instead of $45\ N.m.s/rad$in the baseline

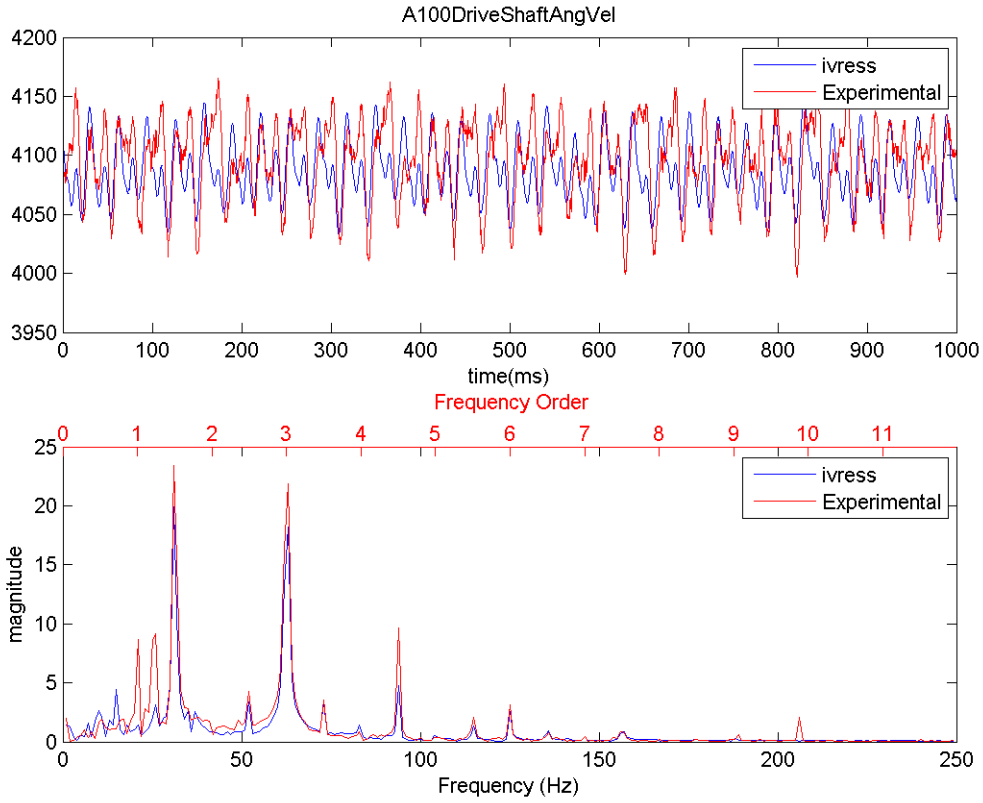

Figure 218 Drive shaft angular velocity in the A100 operation range with drive shaft damping decreased to $35 N.m.s/rad$ instead of $45\ N.m.s/rad$ in the baseline

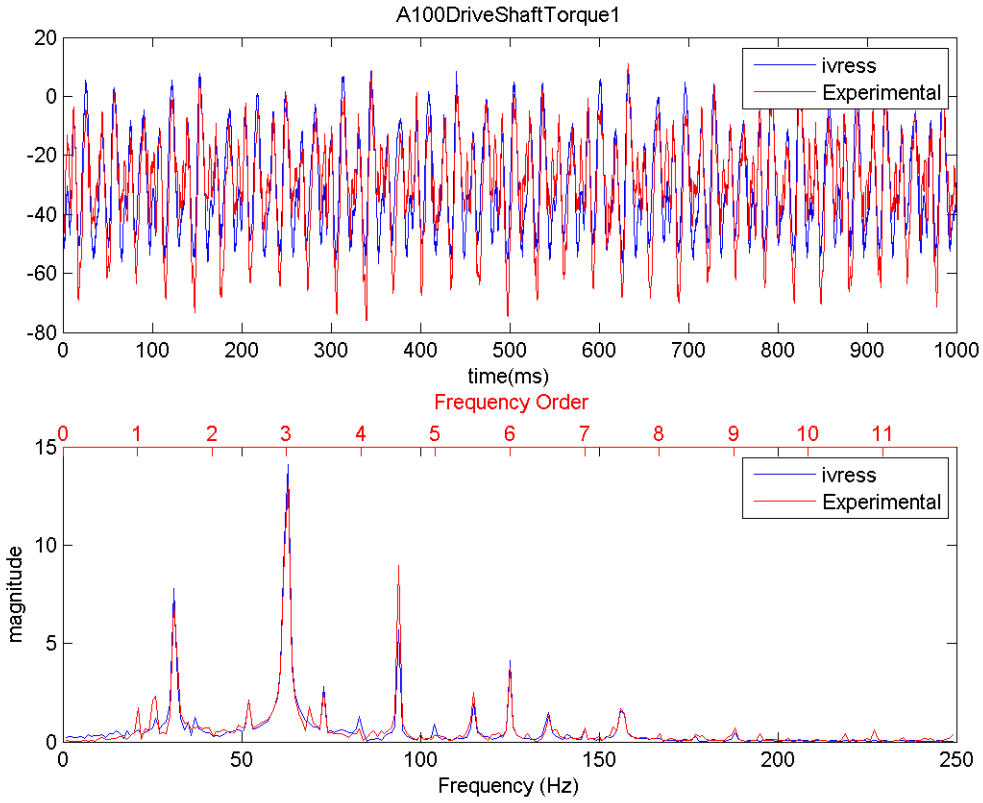

Figure 219 Drive shaft torque in the A100 operation range with drive shaft damping decreased to $35 N.m.s/rad$ instead of $45\ N.m.s/rad$ in the baseline

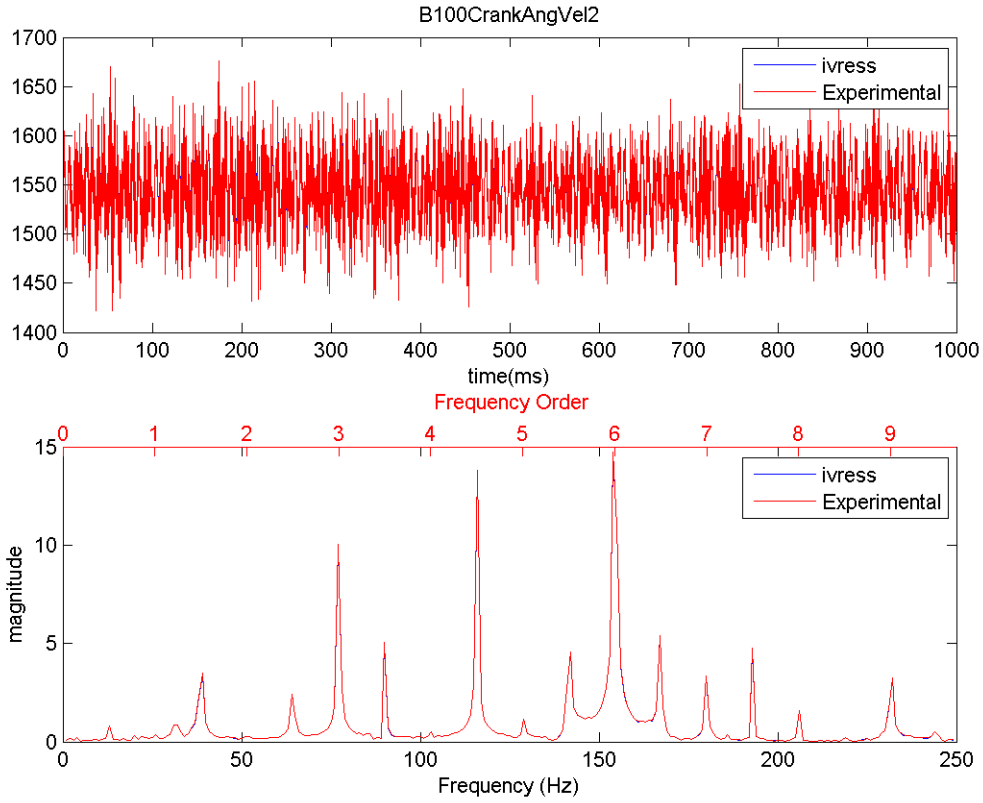

Figure 220 Crankshaft angular velocity in the B100 operation range with drive shaft damping decreased to $35 N.m.s/rad$ instead of $45\ N.m.s/rad$in the baseline

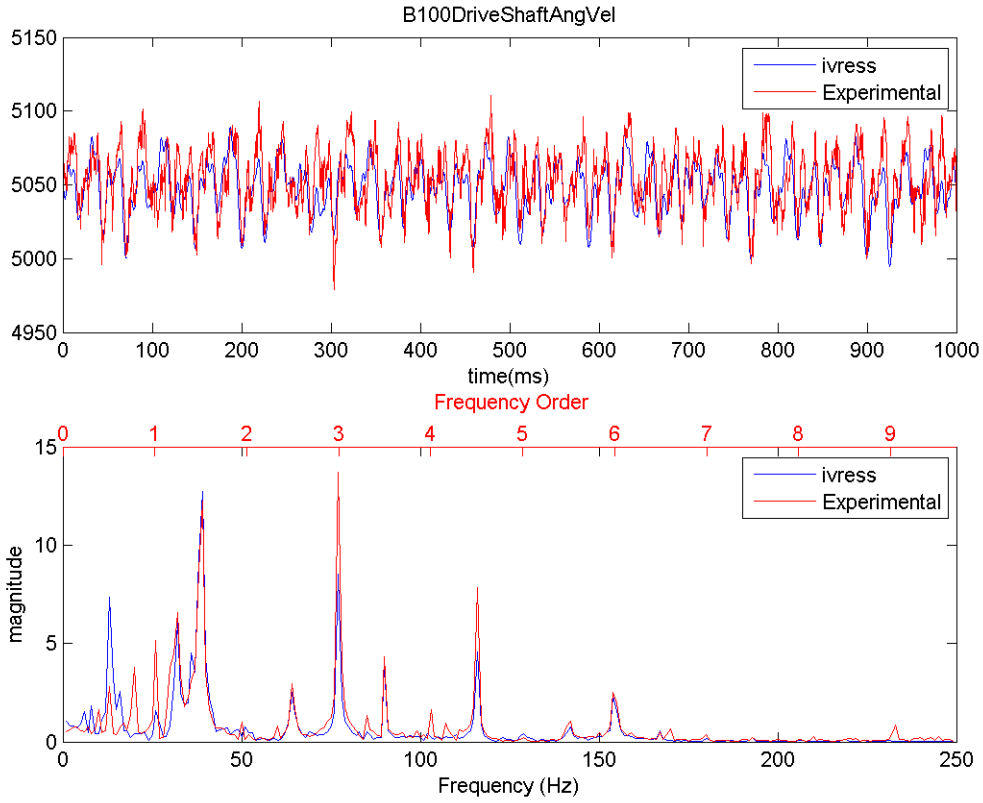

Figure 221 Drive shaft angular velocity in the B100 operation range with drive shaft damping decreased to $35 N.m.s/rad$ instead of $45\ N.m.s/rad$ in the baseline

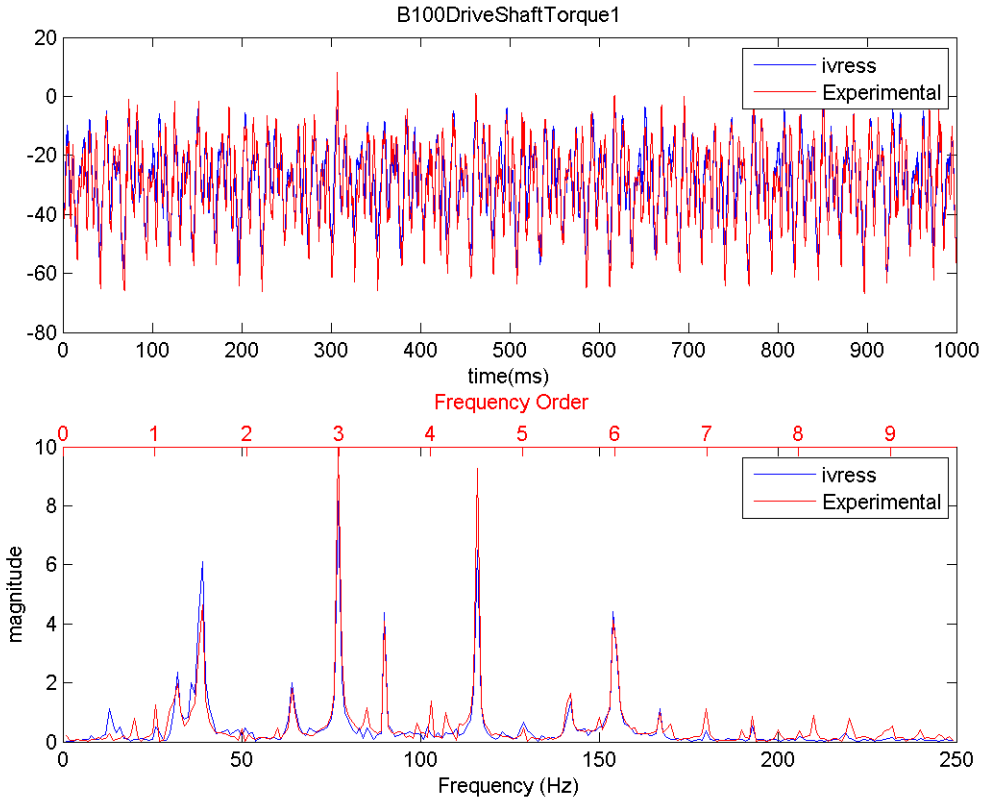

Figure 222 Drive shaft torque in the B100 operation range with drive shaft damping decreased to $35 N.m.s/rad$ instead of $45\ N.m.s/rad$ in the baseline

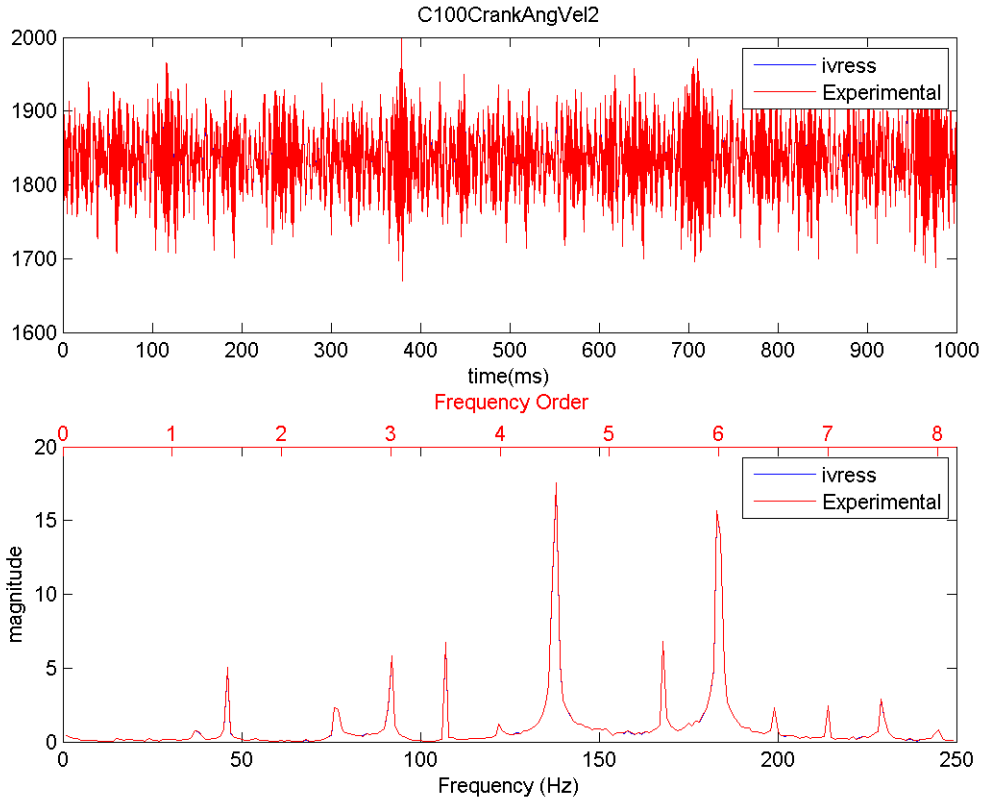

Figure 223 Crankshaft angular velocity in the C100 operation range with drive shaft damping decreased to $35 N.m.s/rad$ instead of $45\ N.m.s/rad$in the baseline

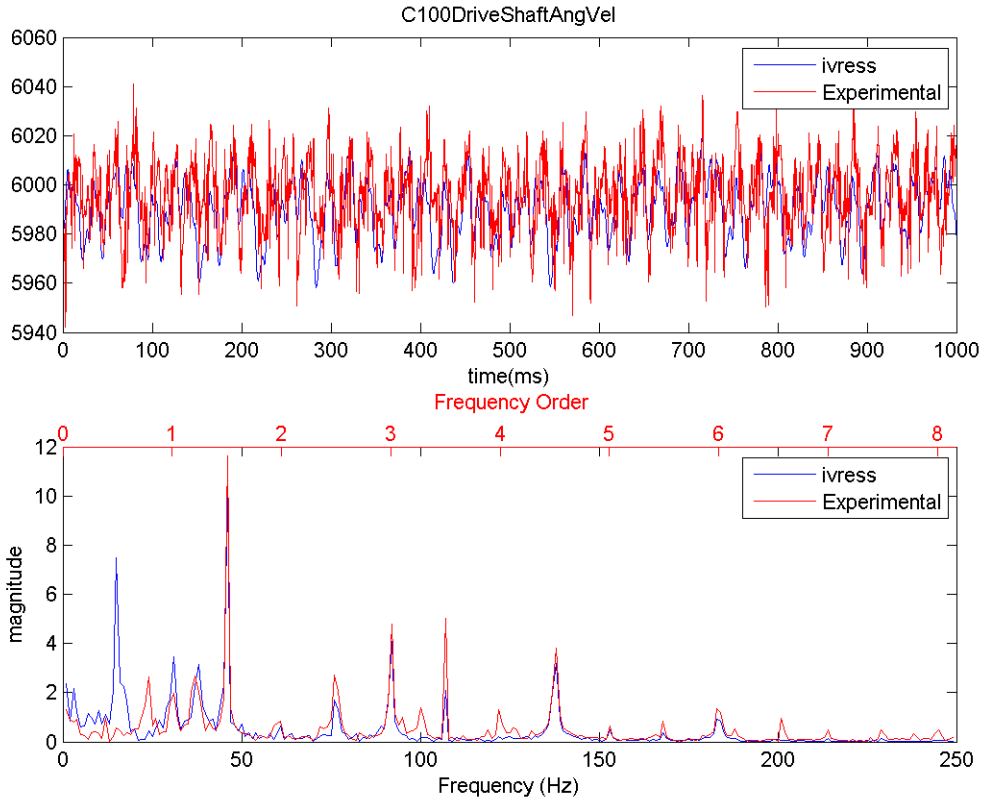

Figure 224 Drive shaft angular velocity in the C100 operation range with drive shaft damping decreased to $35 N.m.s/rad$ instead of $45\ N.m.s/rad$ in the baseline

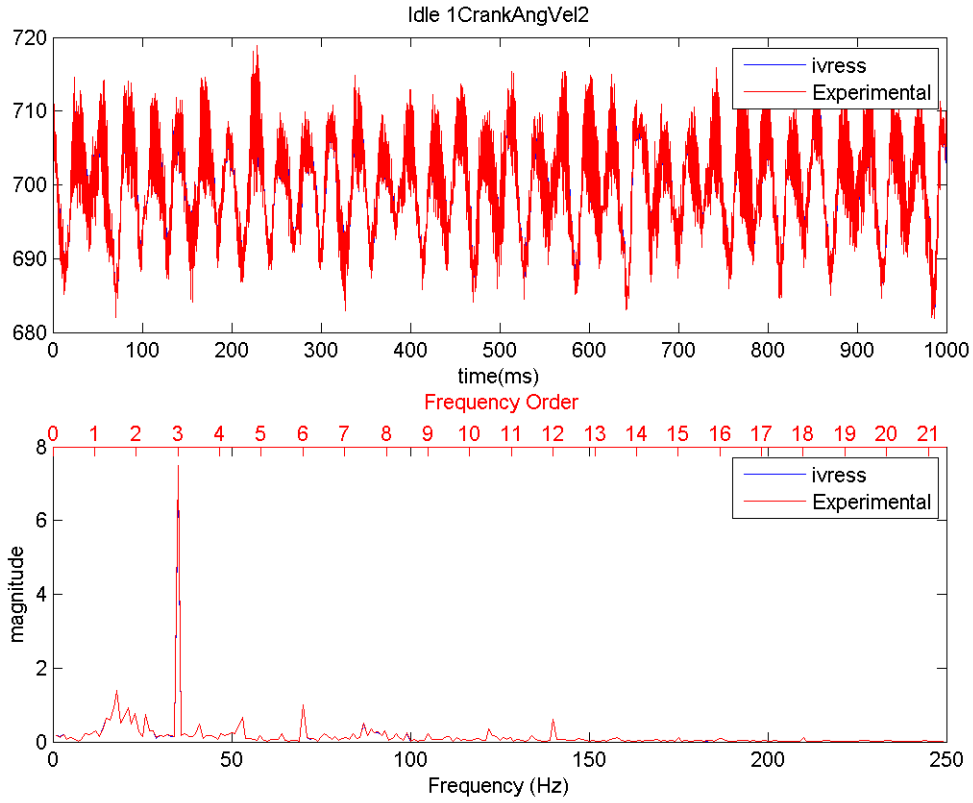

Figure 225 Crankshaft angular velocity in the idle operation range with drive shaft damping decreased to $35 N.m.s/rad$ instead of $45\ N.m.s/rad$in the baseline

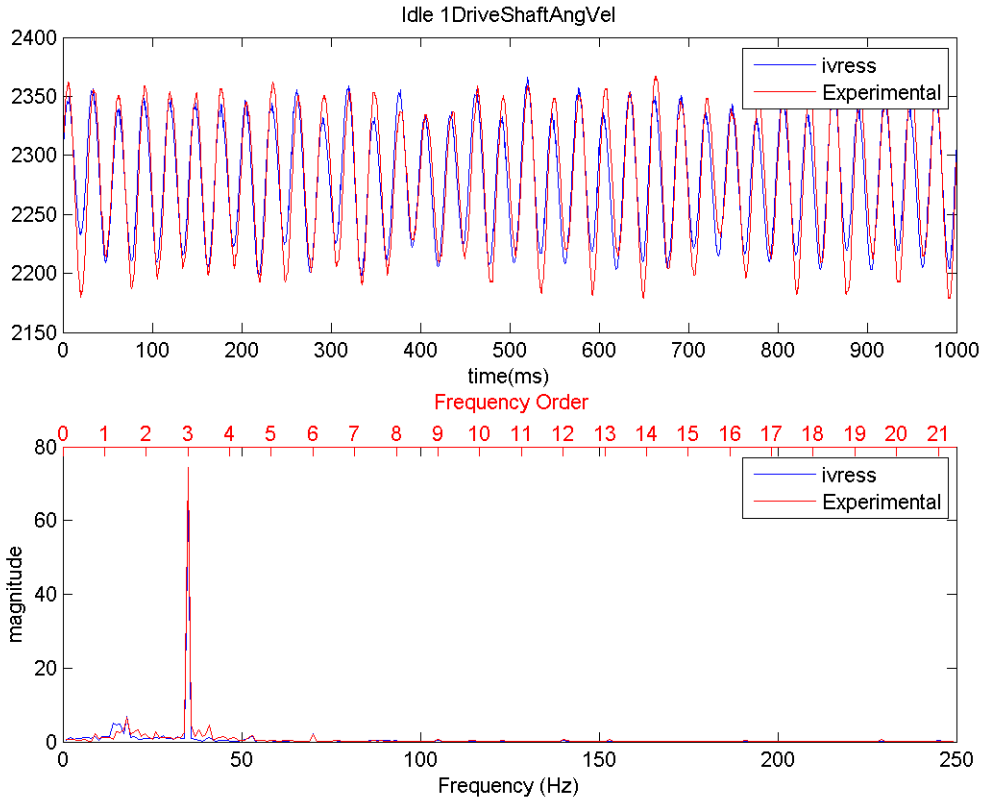

Figure 226 Drive shaft angular velocity in the idle operation range with drive shaft damping decreased to $35 N.m.s/rad$ instead of $45\ N.m.s/rad$ in the baseline

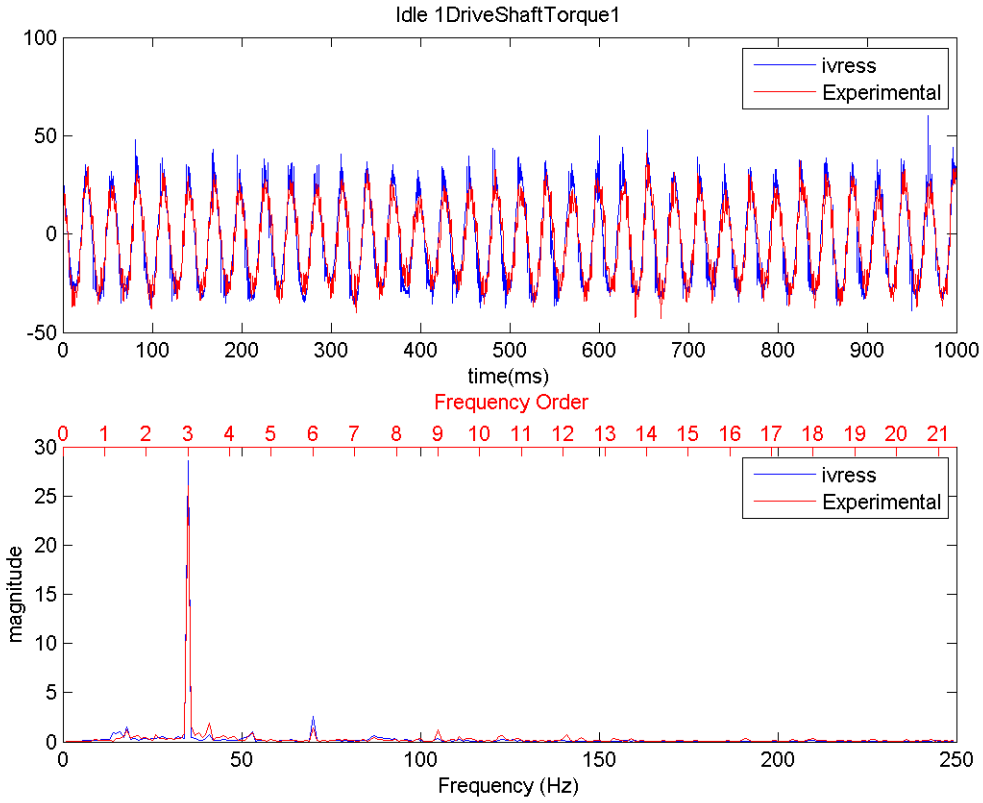

Figure 227 Drive shaft torque in the idle operation range with drive shaft damping decreased to $35 N.m.s/rad$ instead of $45\ N.m.s/rad$ in the baseline

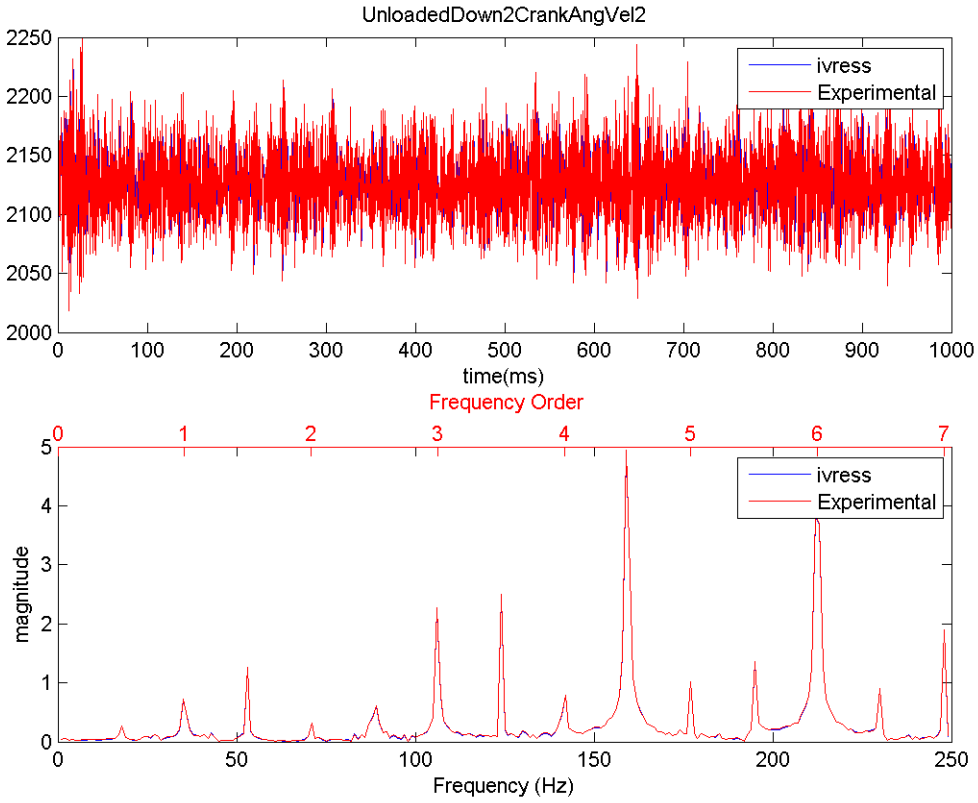

Figure 228 Crankshaft angular velocity in the UnloadedDown operation range with drive shaft damping decreased to $35 N.m.s/rad$ instead of $45\ N.m.s/rad$in the baseline

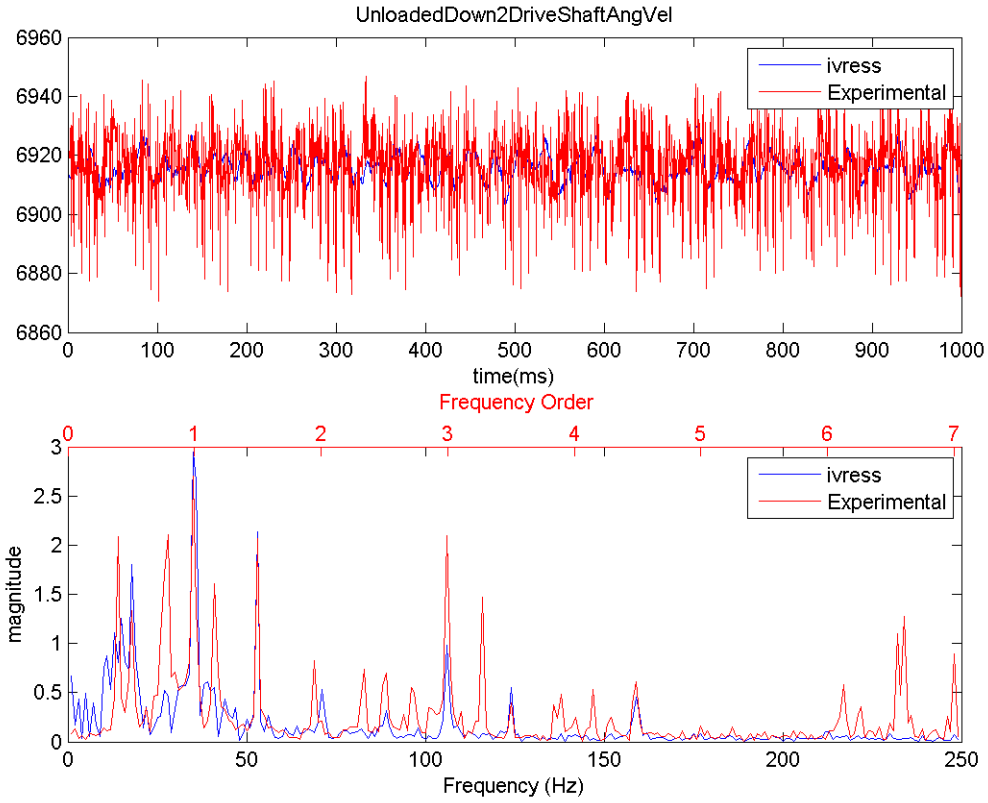

Figure 229 Drive shaft angular velocity in the UnloadedDown operation range with drive shaft damping decreased to $35 N.m.s/rad$ instead of $45\ N.m.s/rad$in the baseline

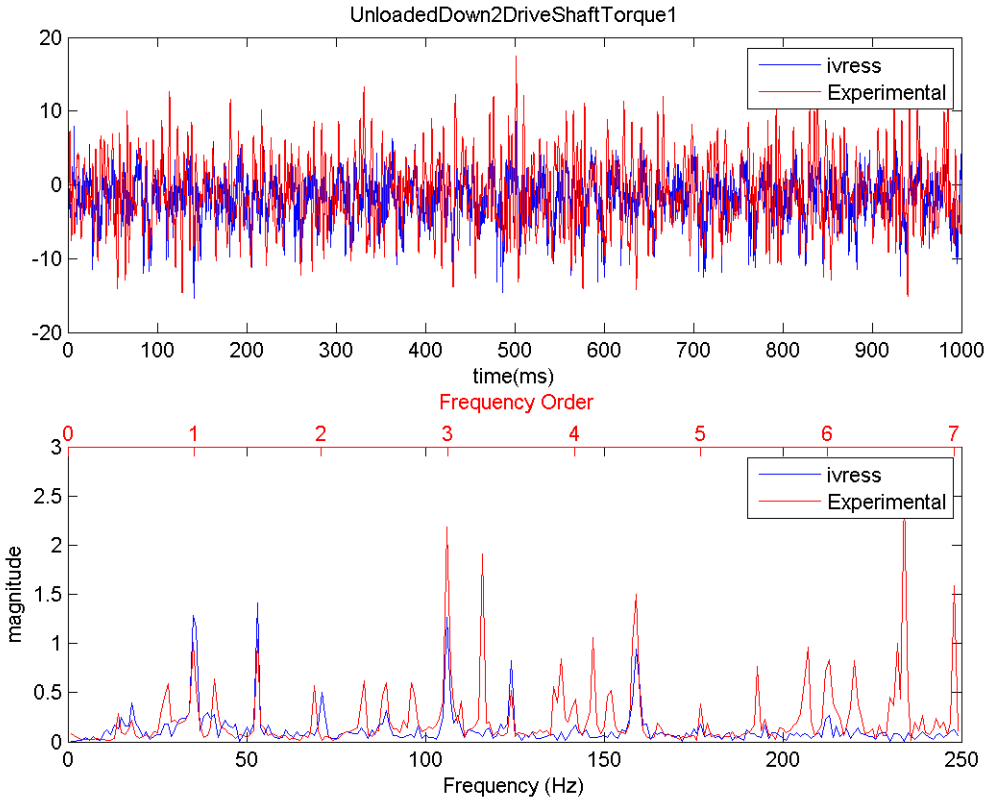

Figure 230 Drive shaft torque in the UnloadedDown operation range with drive shaft damping decreased to $35 N.m.s/rad$ instead of $45\ N.m.s/rad$in the baseline

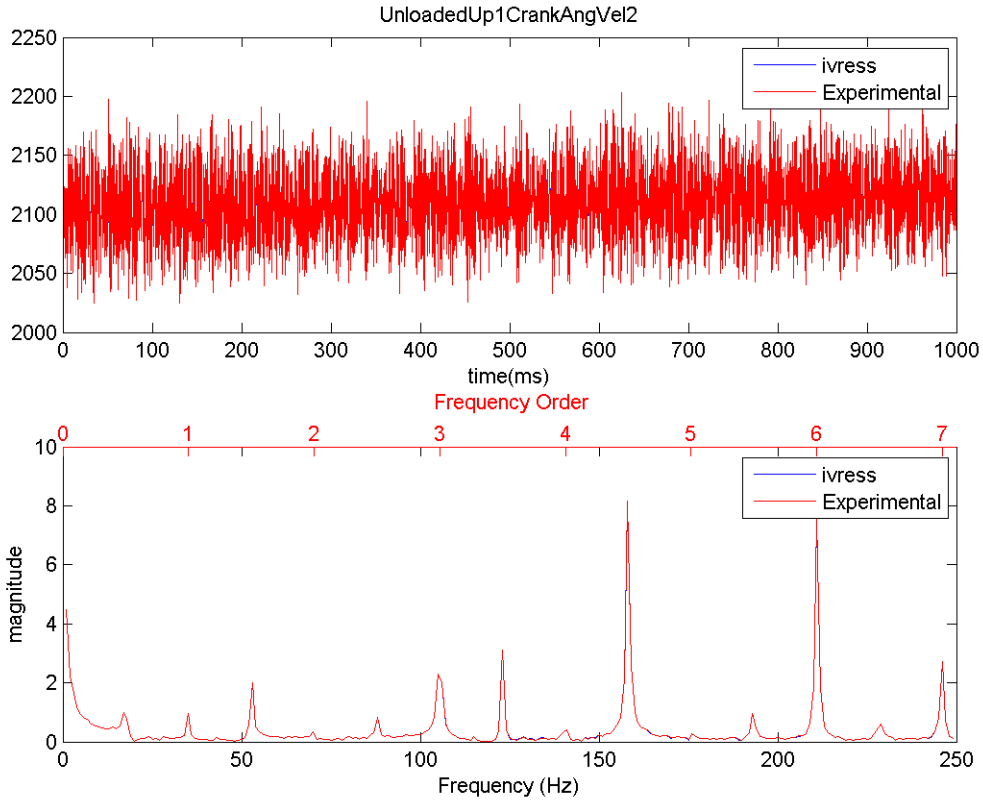

Figure 231 Crankshaft angular velocity in the UnloadedUp operation range with drive shaft damping decreased to $35 N.m.s/rad$ instead of $45\ N.m.s/rad$in the baseline

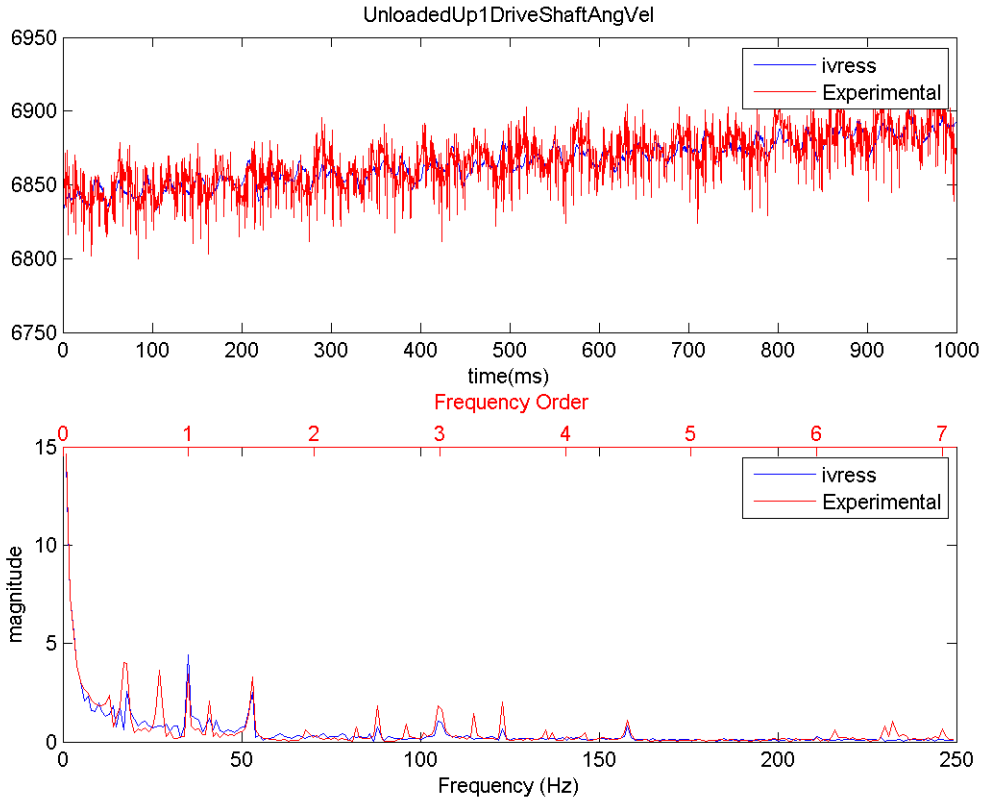

Figure 232 Drive shaft angular velocity in the UnloadedUp operation range with drive shaft damping decreased to $35 N.m.s/rad$ instead of $45\ N.m.s/rad$ in the baseline

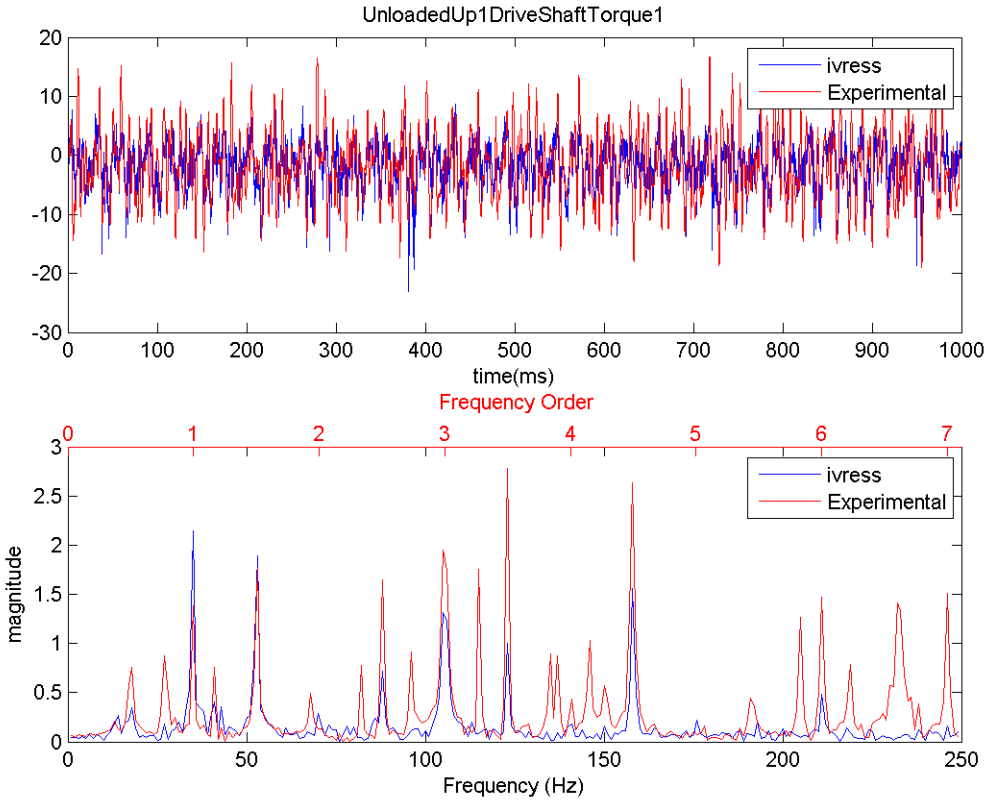

Figure 233 Drive shaft torque in the UnloadedUp operation range with drive shaft damping decreased to $35 N.m.s/rad$ instead of $45\ N.m.s/rad$in the baseline

14 Turbine Shaft Torsional Stiffness Decreased To 1000 Nm/rad Instead Of 1442 N/rad

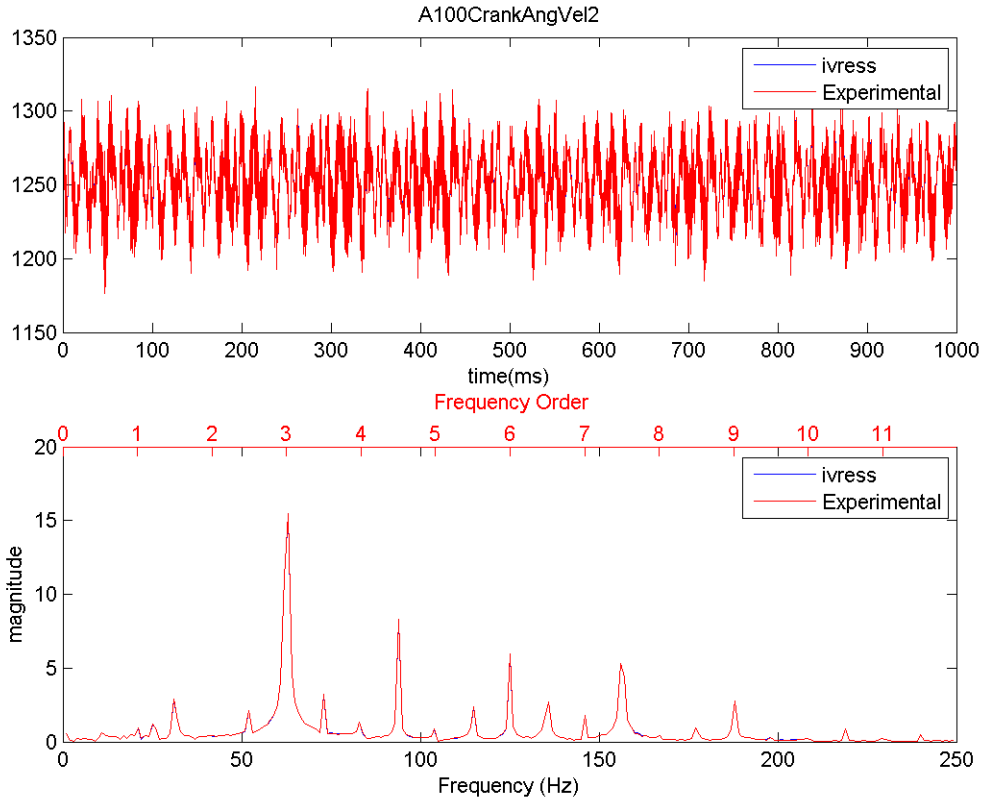

Figure 234 Crankshaft angular velocity in the A100 operation range with turbine shaft torsional stiffness decreased to $\mathbf{1000\ Nm/rad}$ instead of $\mathbf{1442\ Nm/rad}$

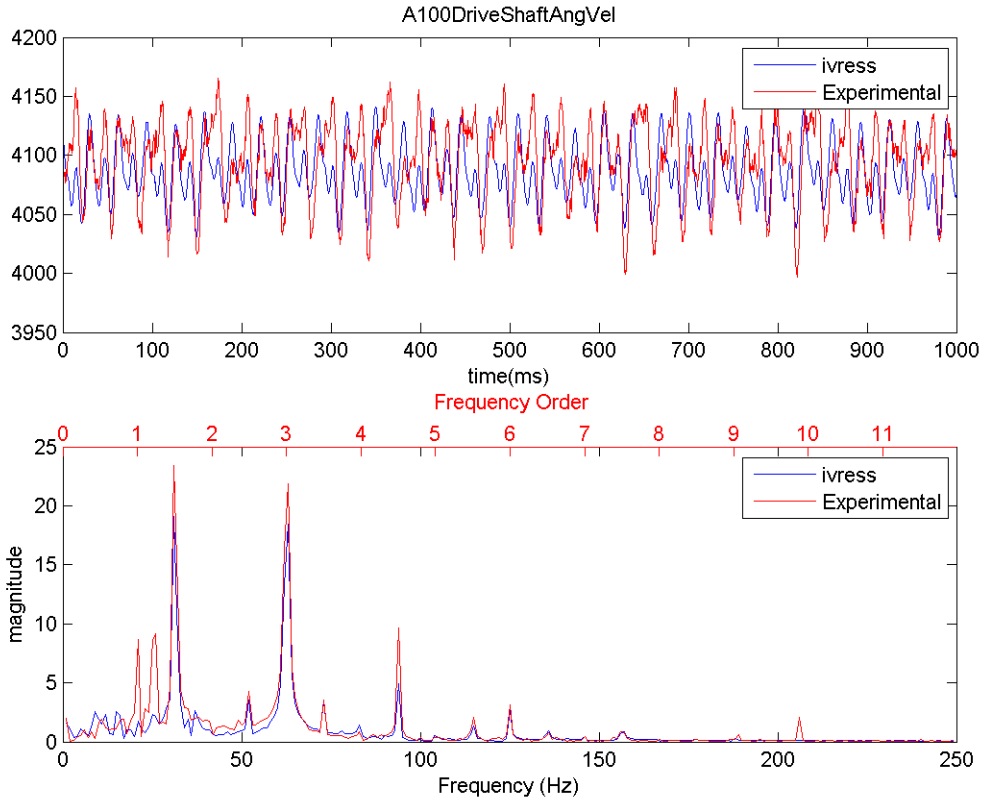

Figure 235 Drive shaft angular velocity in the A100 operation range with turbine shaft torsional stiffness decreased to 1000 Nm/rad instead of 1442 Nm/rad

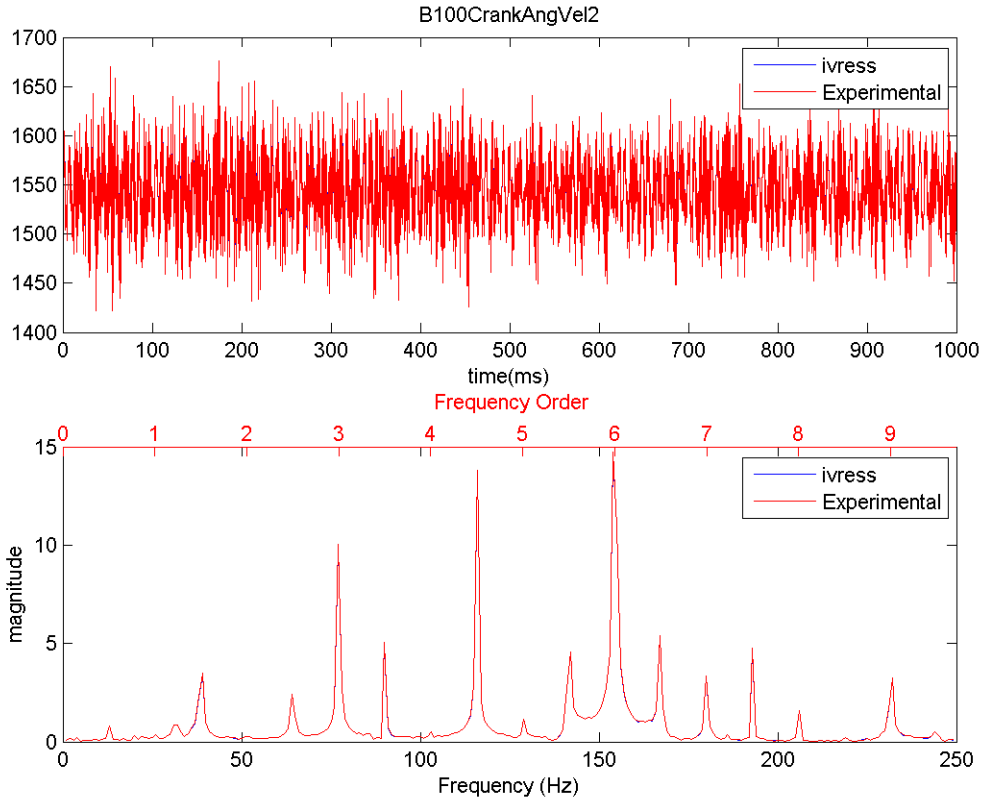

Figure 236 Crankshaft angular velocity in the B100 operation range with turbine shaft torsional stiffness decreased to 1000 Nm/rad instead of 1442 Nm/rad

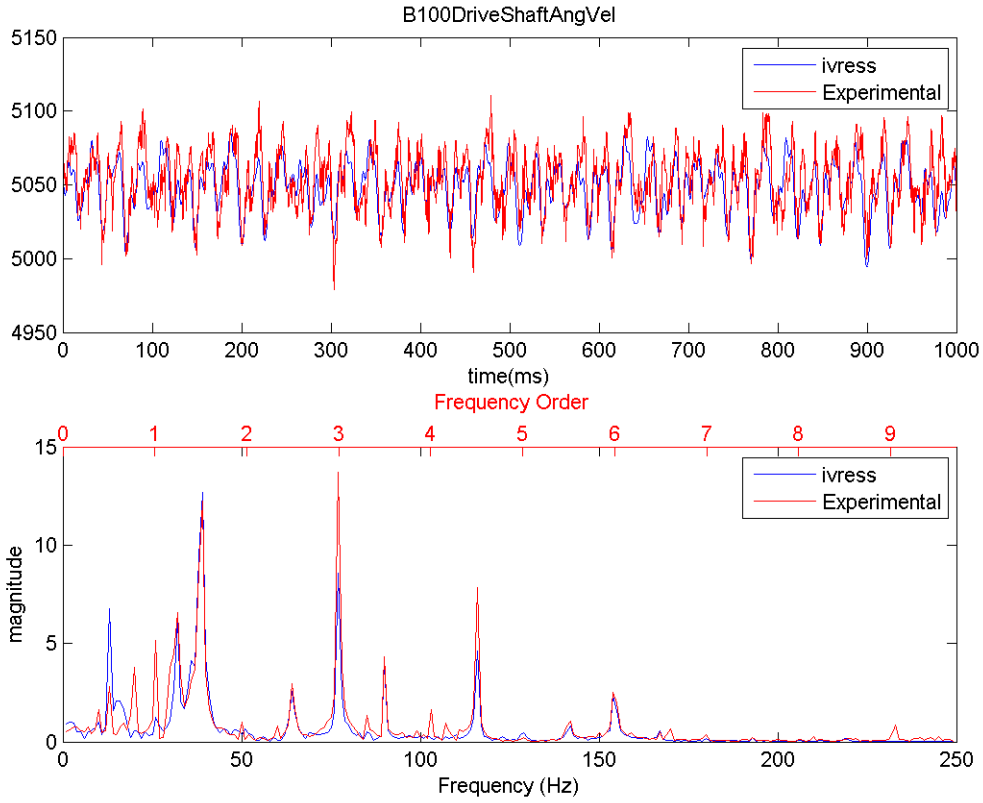

Figure 237 Drive shaft angular velocity in the B100 operation range with turbine shaft torsional stiffness decreased to 1000 Nm/rad instead of 1442 Nm/rad

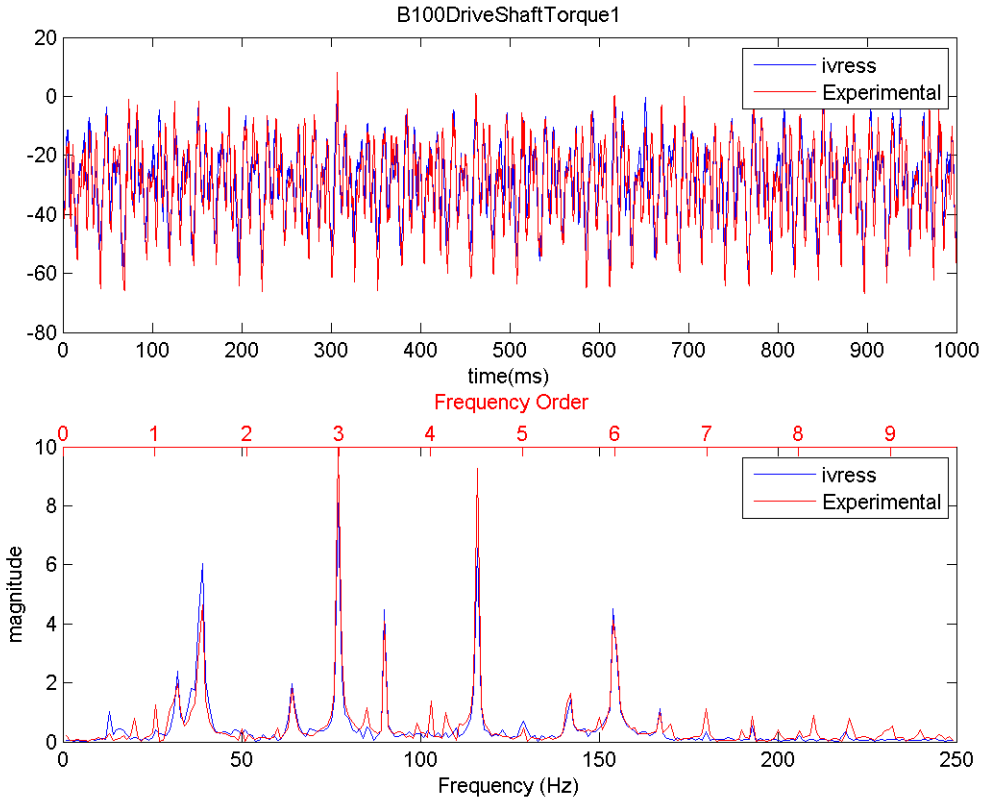

Figure 238 Drive shaft torque in the B100 operation range with turbine shaft torsional stiffness decreased to 1000 Nm/rad instead of 1442 Nm/rad

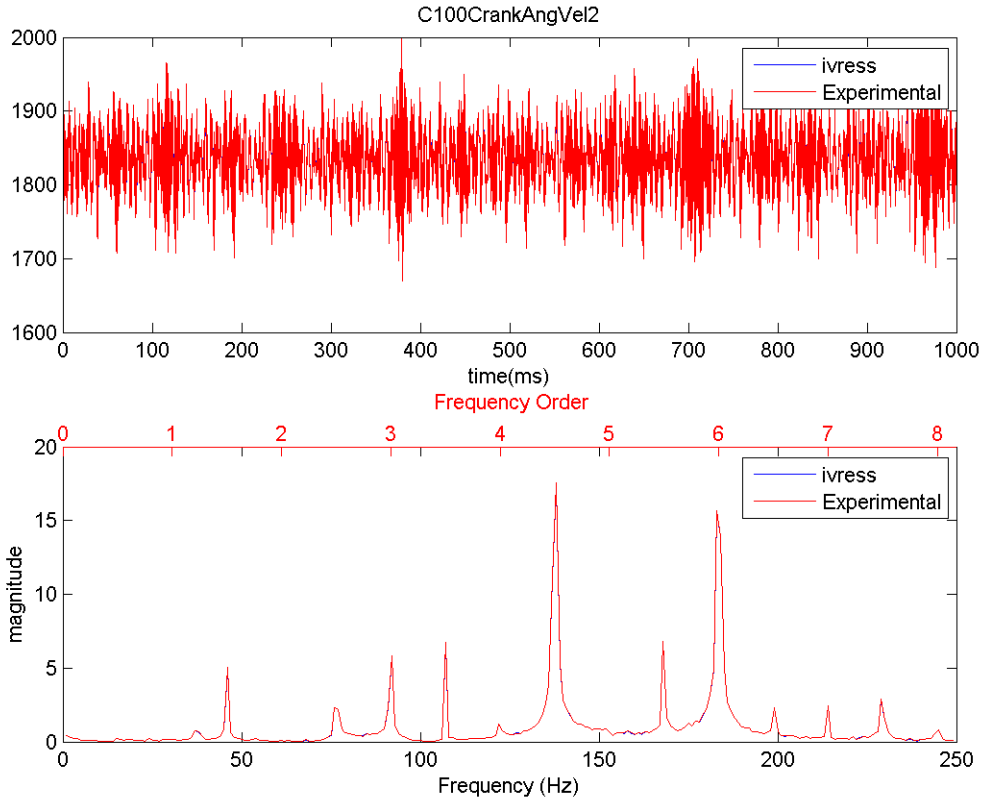

Figure 239 Crankshaft angular velocity in the C100 operation range with turbine shaft torsional stiffness decreased to 1000 Nm/rad instead of 1442 Nm/rad

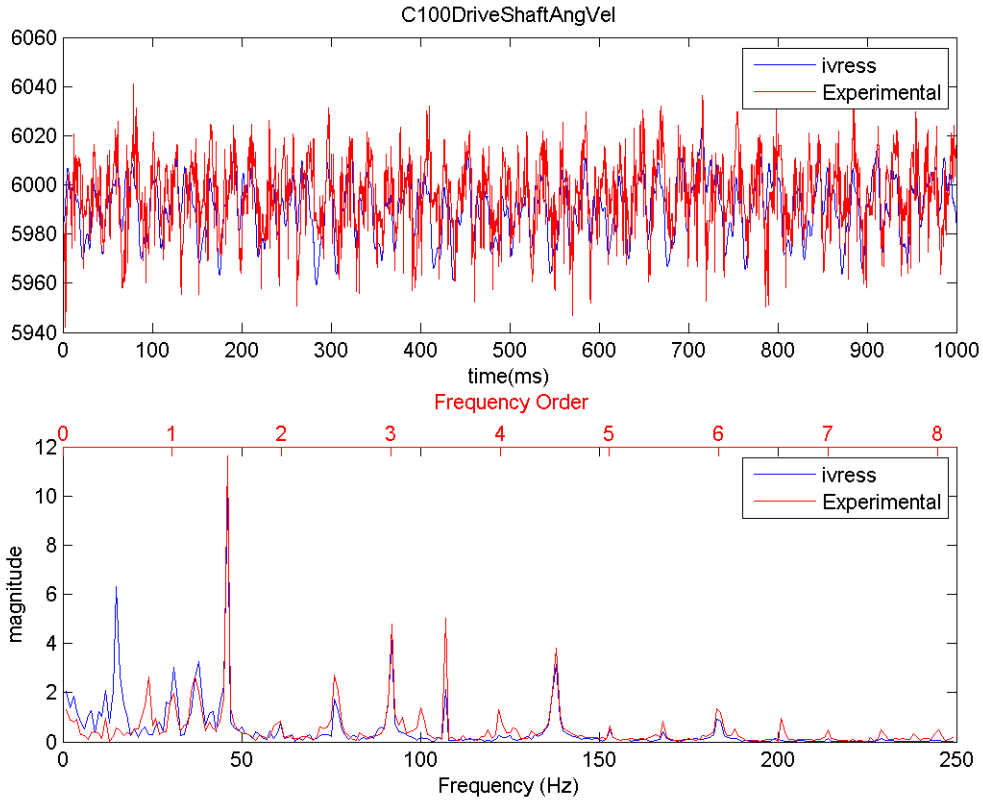

Figure 240 Drive shaft angular velocity in the C100 operation range with turbine shaft torsional stiffness decreased to 1000 Nm/rad instead of 1442 Nm/rad

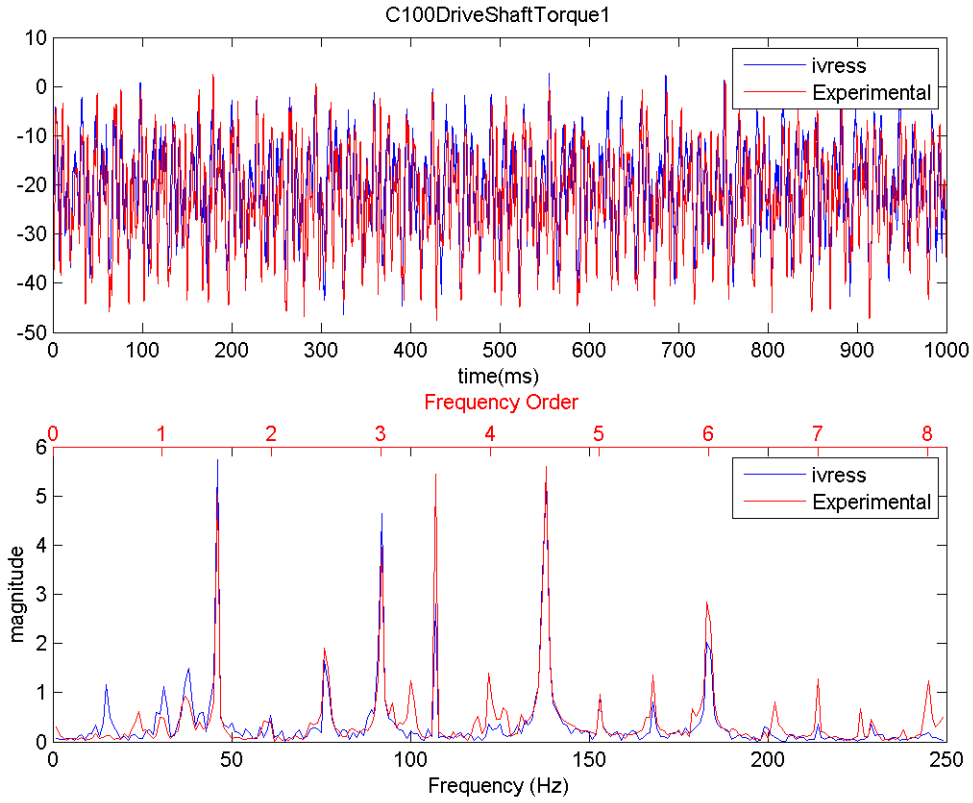

Figure 241 Drive shaft torque in the C100 operation range with turbine shaft torsional stiffness decreased to 1000 Nm/rad instead of 1442 Nm/rad

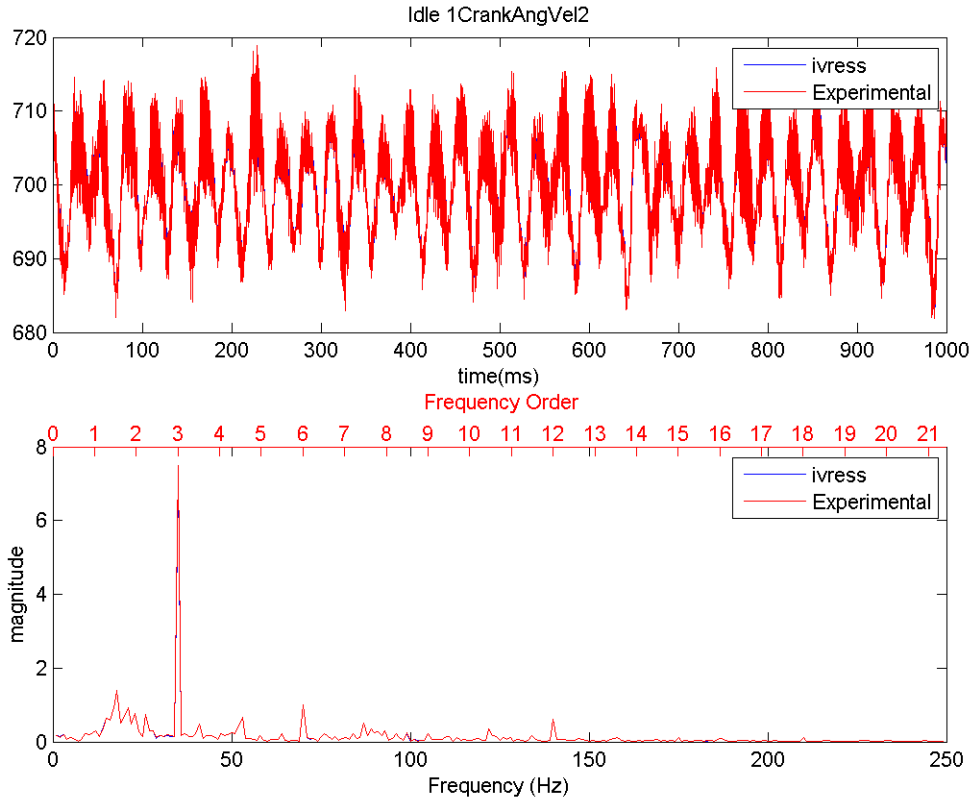

Figure 242 Crankshaft angular velocity in the idle operation range with turbine shaft torsional stiffness decreased to 1000 Nm/rad instead of 1442 Nm/rad

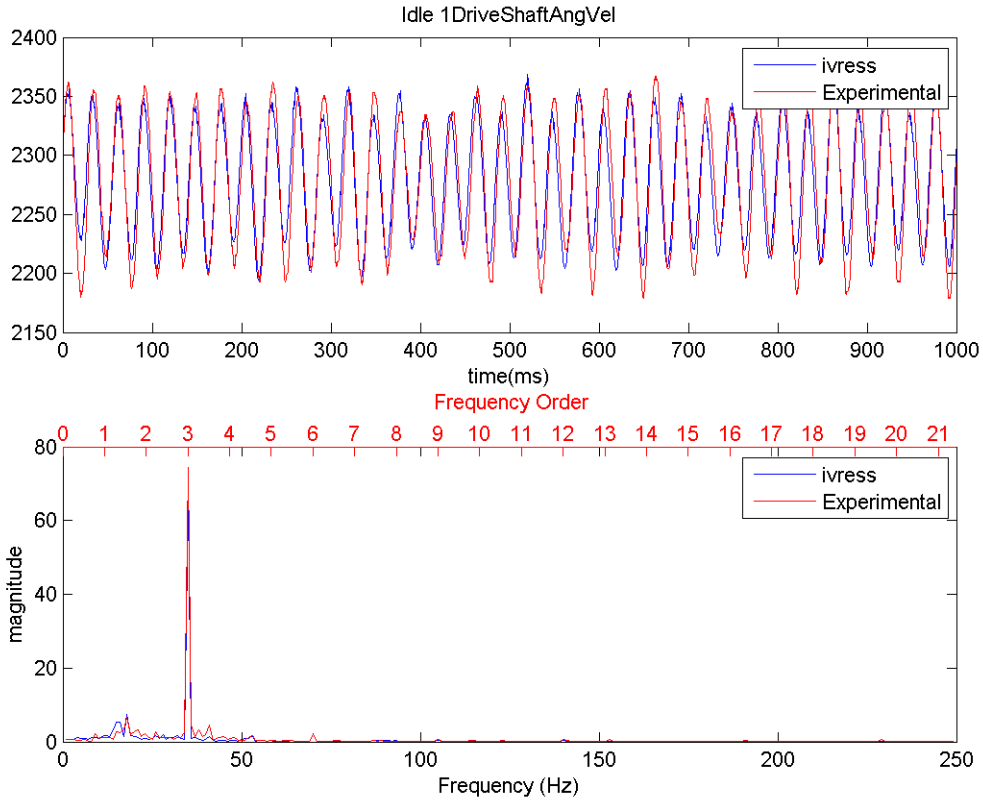

Figure 243 Drive shaft angular velocity in the idle operation range with turbine shaft torsional stiffness decreased to 1000 Nm/rad instead of 1442 Nm/rad

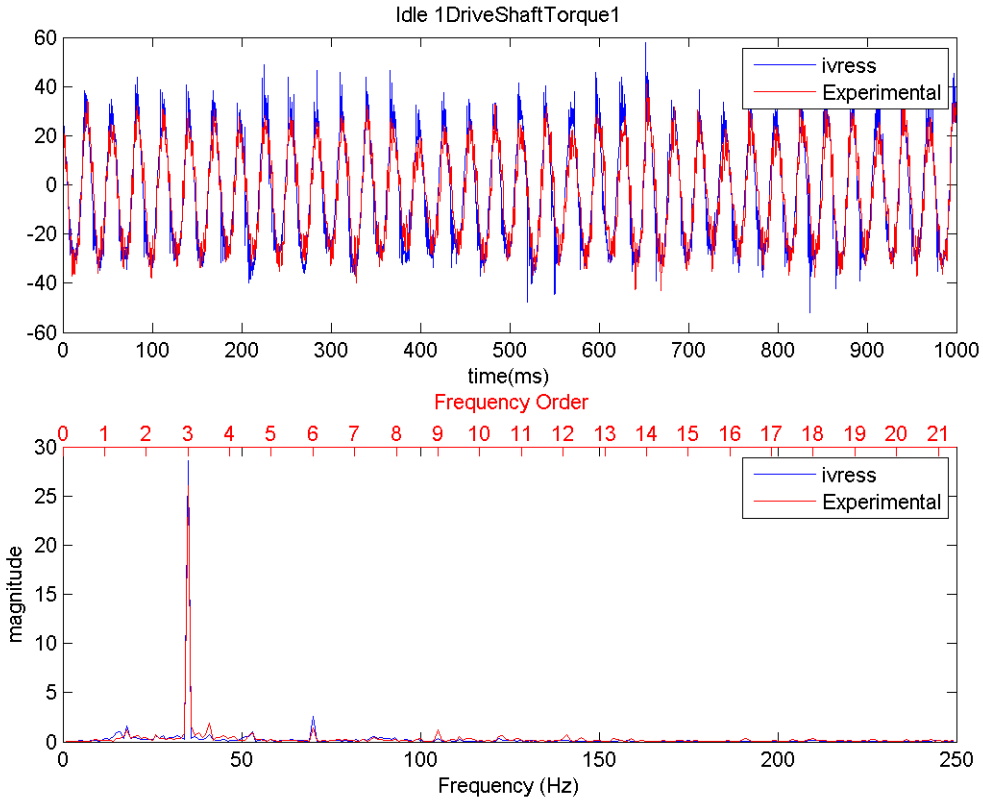

Figure 244 Drive shaft torque in the idle operation range with turbine shaft torsional stiffness decreased to 1000 Nm/rad instead of 1442 Nm/rad

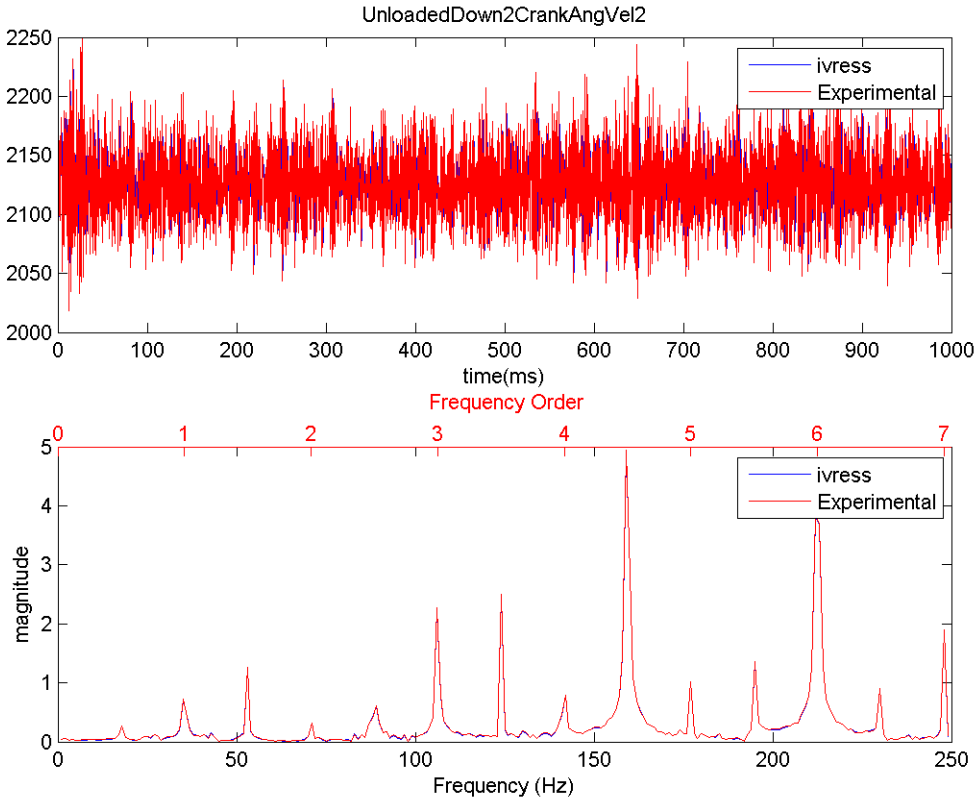

Figure 245 Crankshaft angular velocity in the UnloadedDown operation range with turbine shaft torsional stiffness decreased to 1000 Nm/rad instead of 1442 Nm/rad

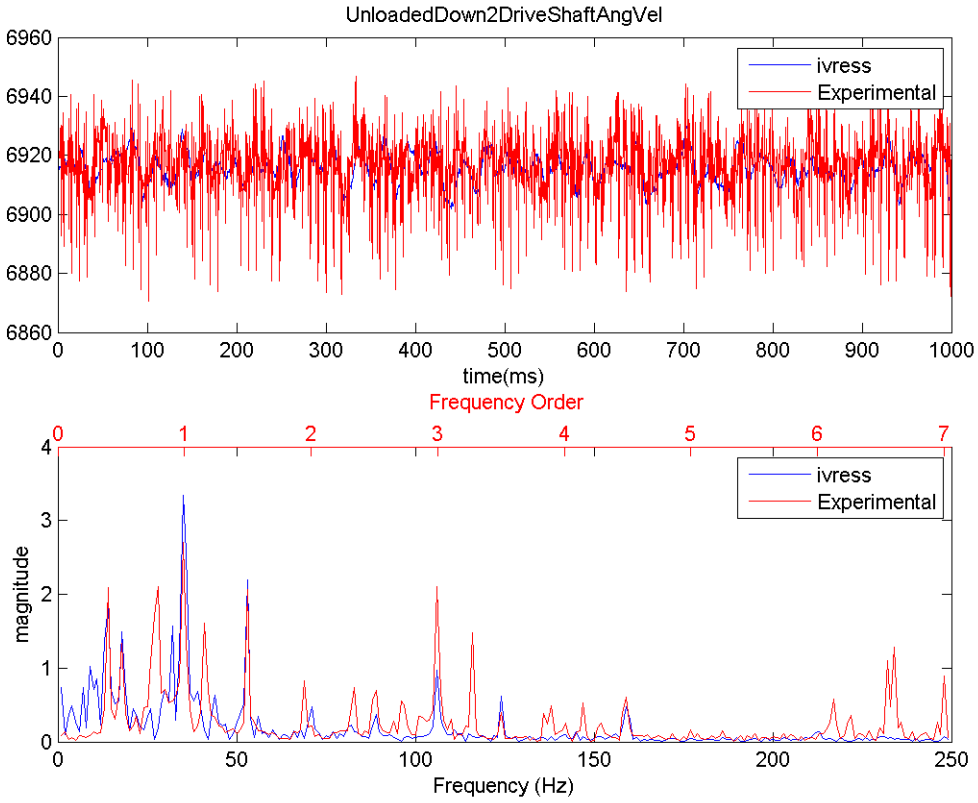

Figure 246 Drive shaft angular velocity in the UnloadedDown operation range with turbine shaft torsional stiffness decreased to 1000 Nm/rad instead of 1442 Nm/rad

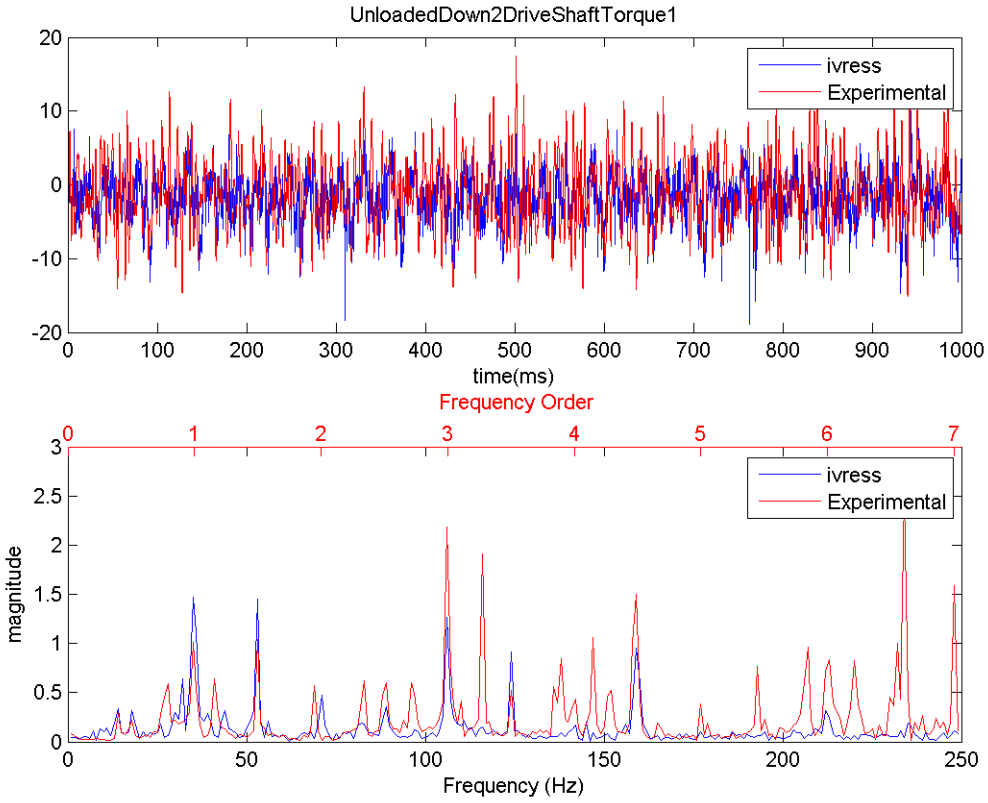

Figure 247 Drive shaft torque in the UnloadedDown operation range with turbine shaft torsional stiffness decreased to 1000 Nm/rad instead of 1442 Nm/rad

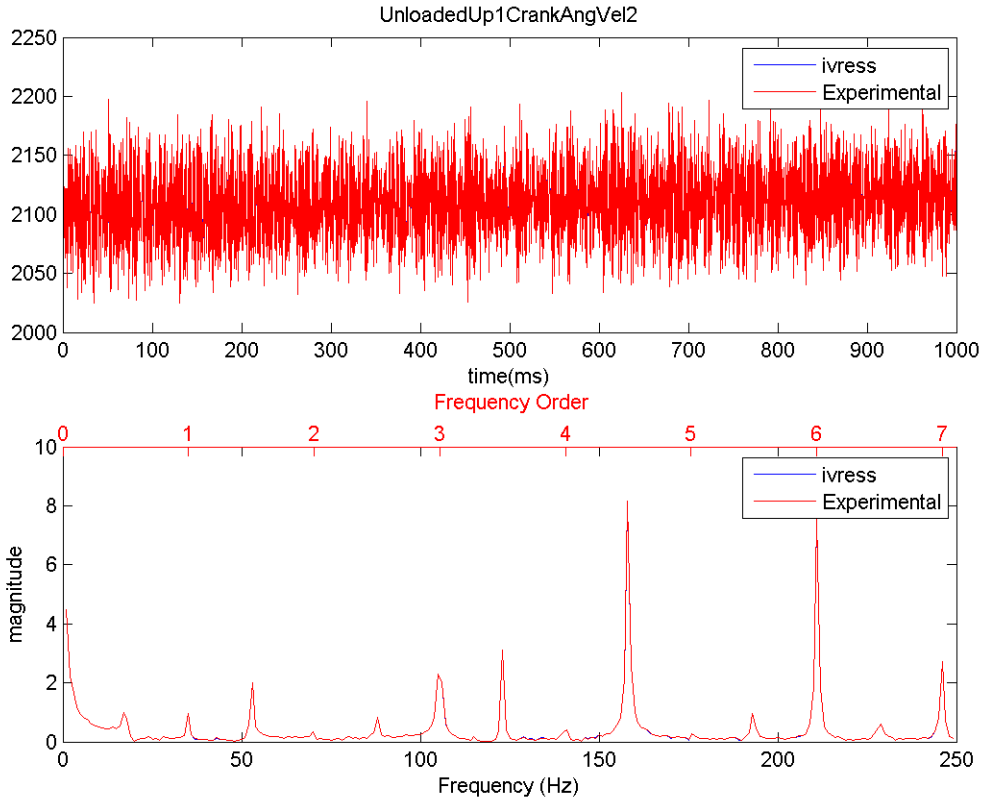

Figure 248 Crankshaft angular velocity in the UnloadedUp operation range with turbine shaft torsional stiffness decreased to 1000 Nm/rad instead of 1442 Nm/rad

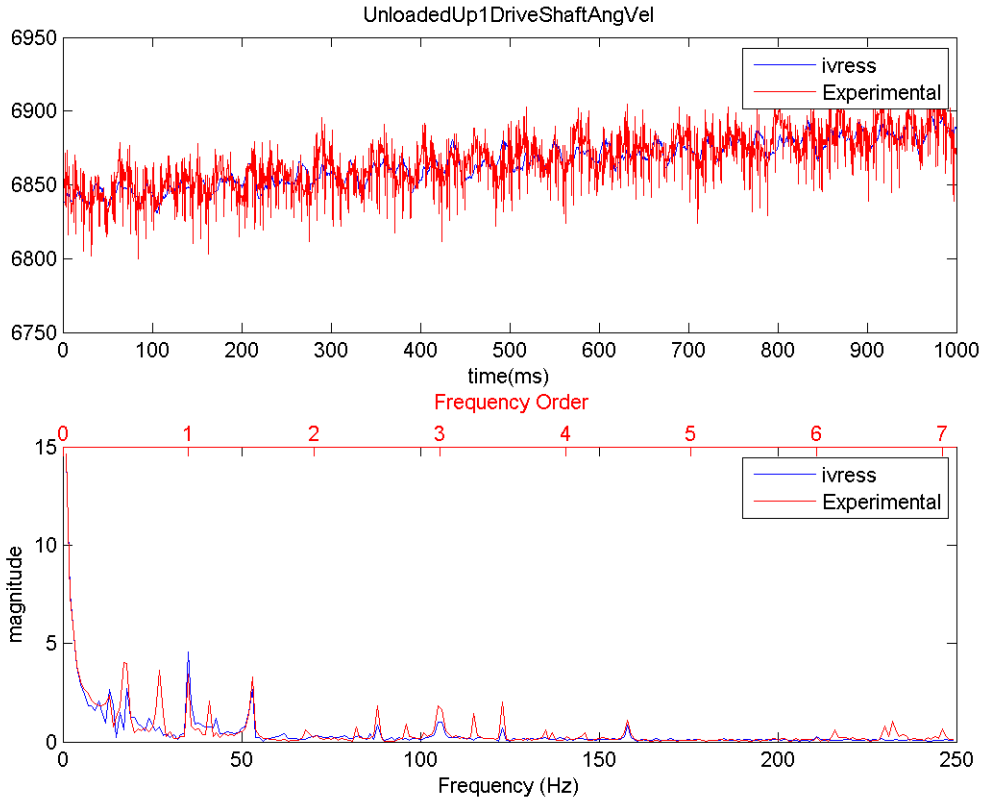

Figure 249 Drive shaft angular velocity in the UnloadedUp operation range with turbine shaft torsional stiffness decreased to 1000 Nm/rad instead of 1442 Nm/rad

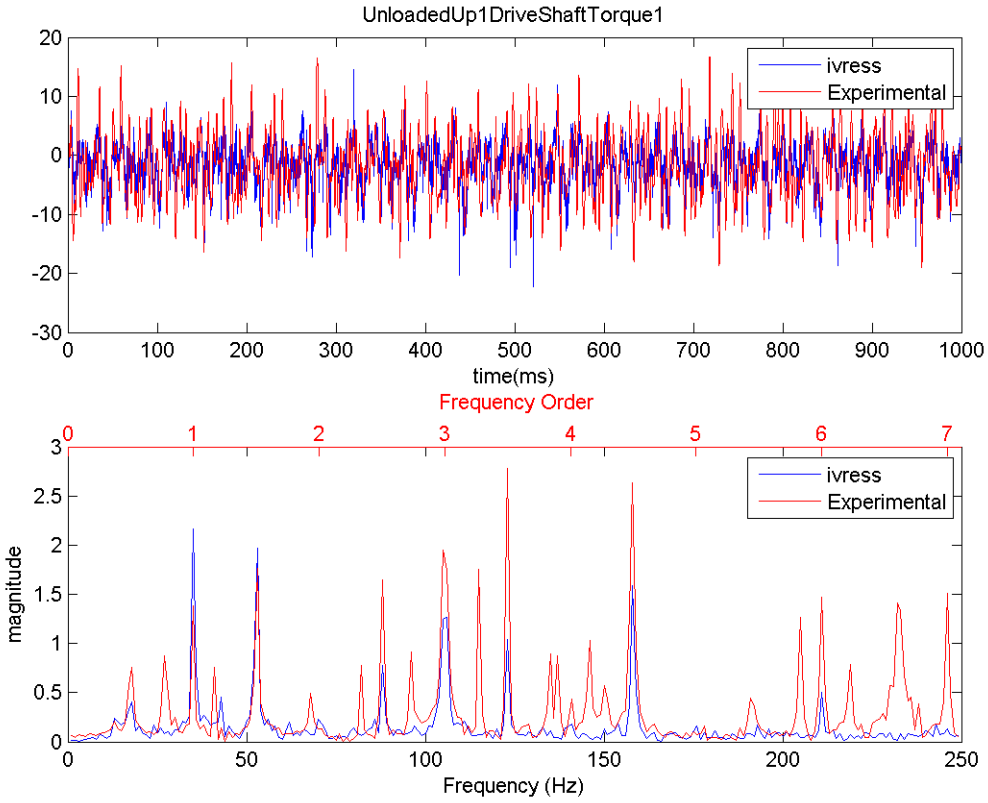

Figure 250 Drive shaft torque in the UnloadedUp operation range with turbine shaft torsional stiffness decreased to 1000 Nm/rad instead of 1442 Nm/rad

15 Turbine Shaft Torsional Damping Decreased To 2 $N.m.s/rad$ Instead Of 4 $N.s/rad$

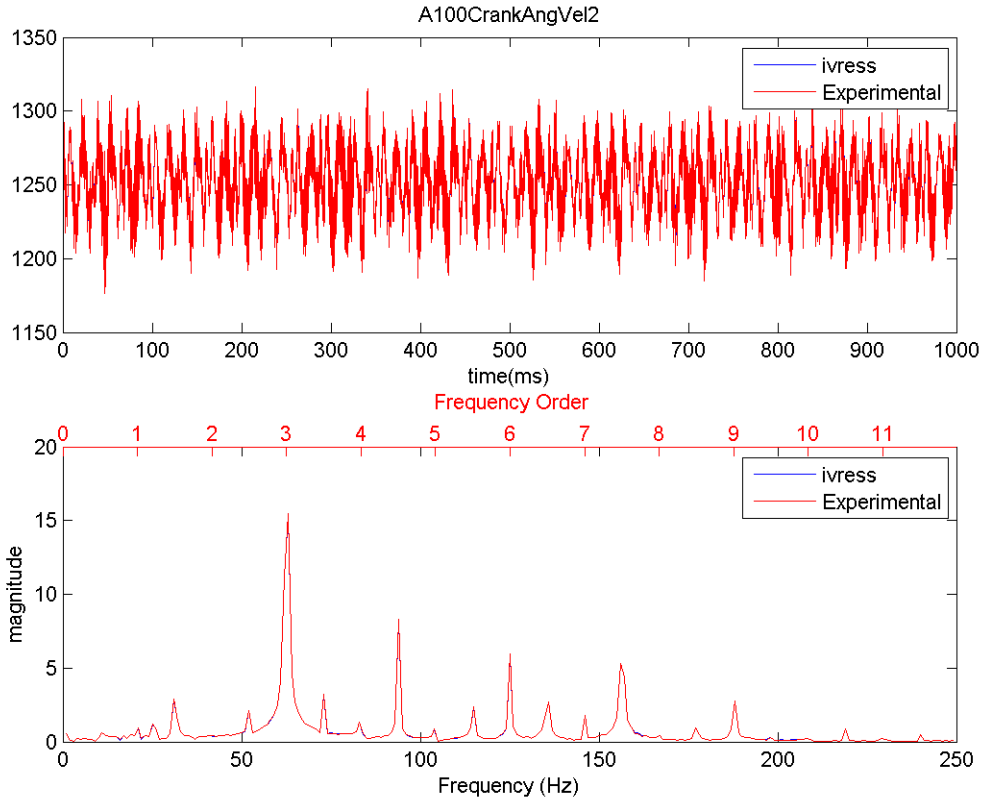

Figure 251 Crankshaft angular velocity in the A100 operation range with turbine shaft torsional damping decreased to 2 $N.m.s/rad$ instead of 4 $N.m.s/rad$

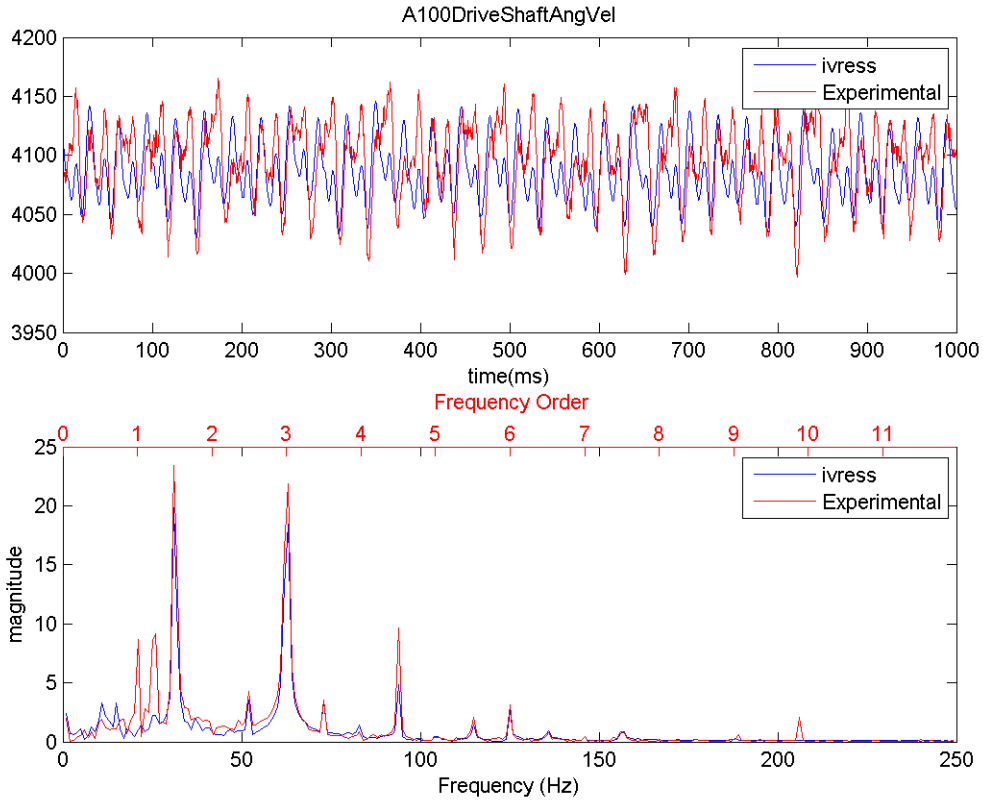

Figure 252 Drive shaft angular velocity in the A100 operation range with turbine shaft torsional damping decreased to 2 $N.m.s/rad$ instead of 4 $N.m.s/rad$

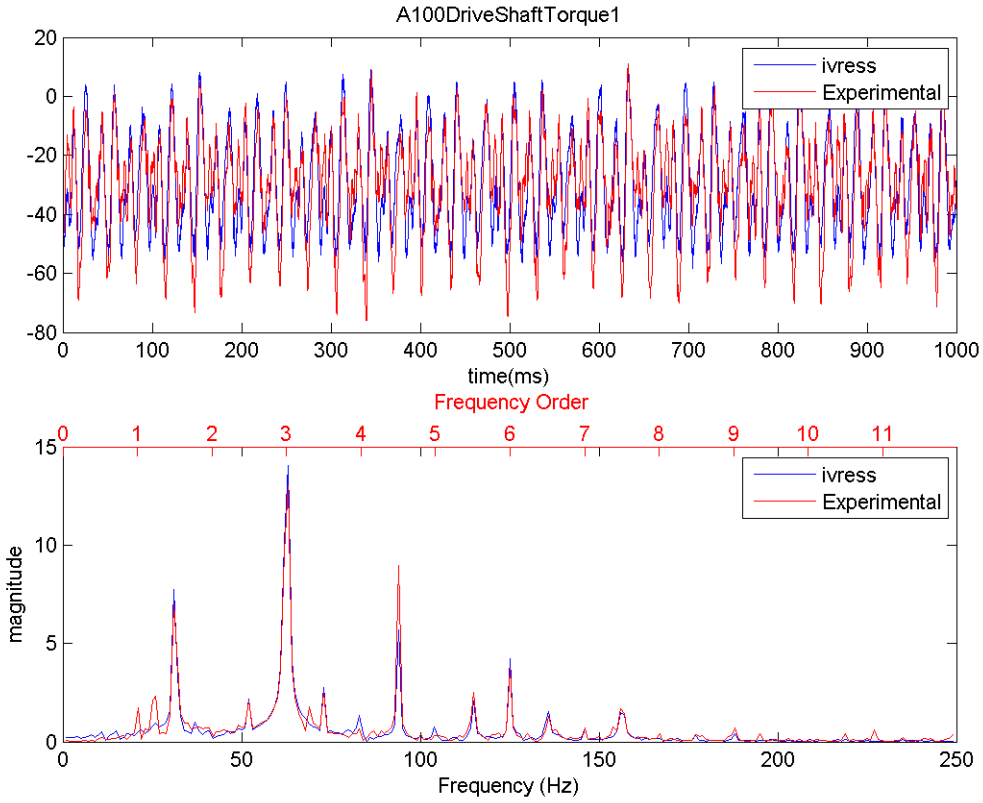

Figure 253 Drive shaft torque in the A100 operation range with turbine shaft torsional damping decreased to 2 $N.m.s/rad$ instead of 4 $N.m.s/rad$

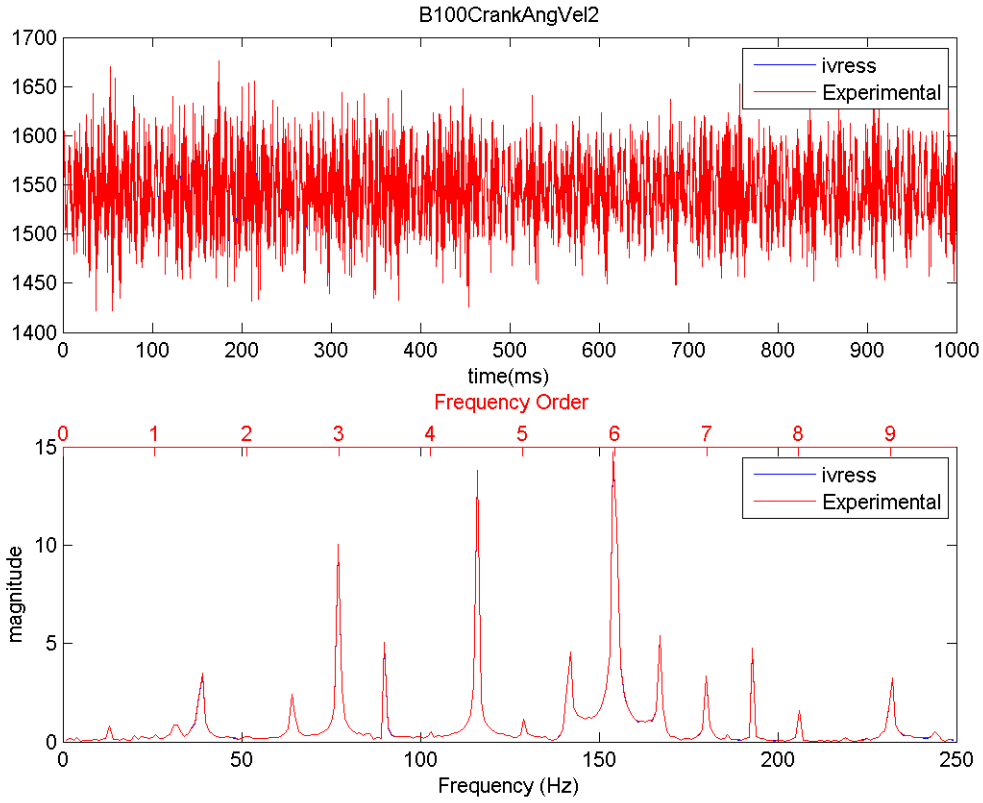

Figure 254 Crankshaft angular velocity in the B100 operation range with turbine shaft torsional damping decreased to 2 $N.m.s/rad$ instead of 4 $N.m.s/rad$

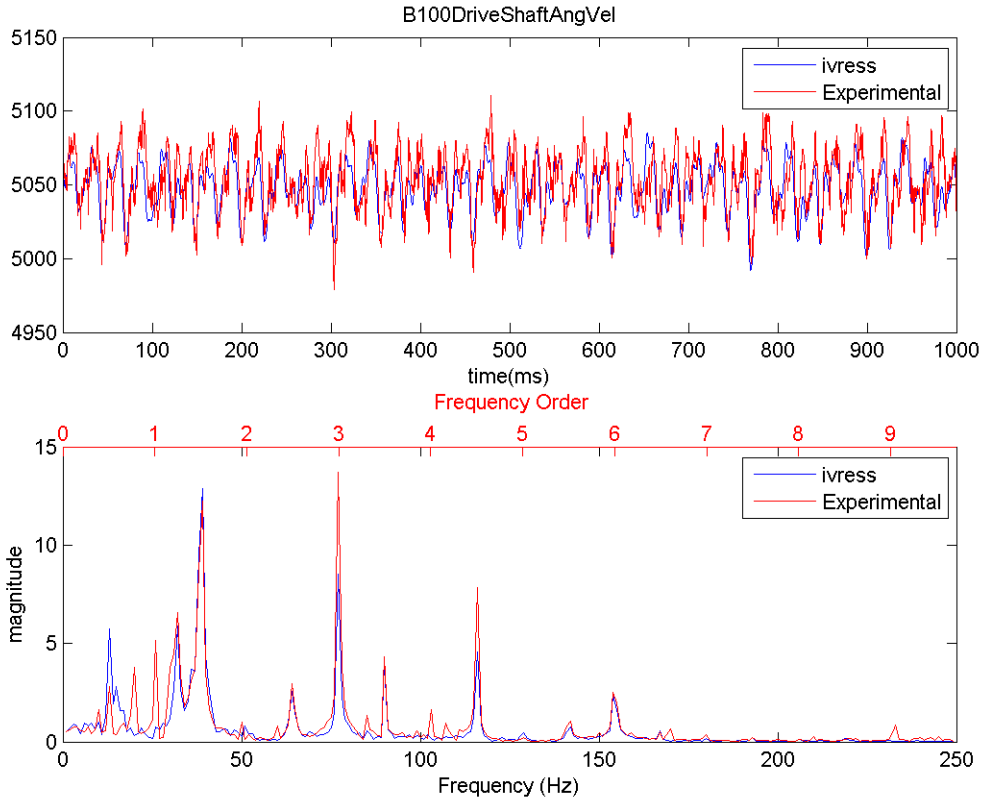

Figure 255 Drive shaft angular velocity in the B100 operation range with turbine shaft torsional damping decreased to 2 $N.m.s/rad$ instead of 4 $N.m.s/rad$

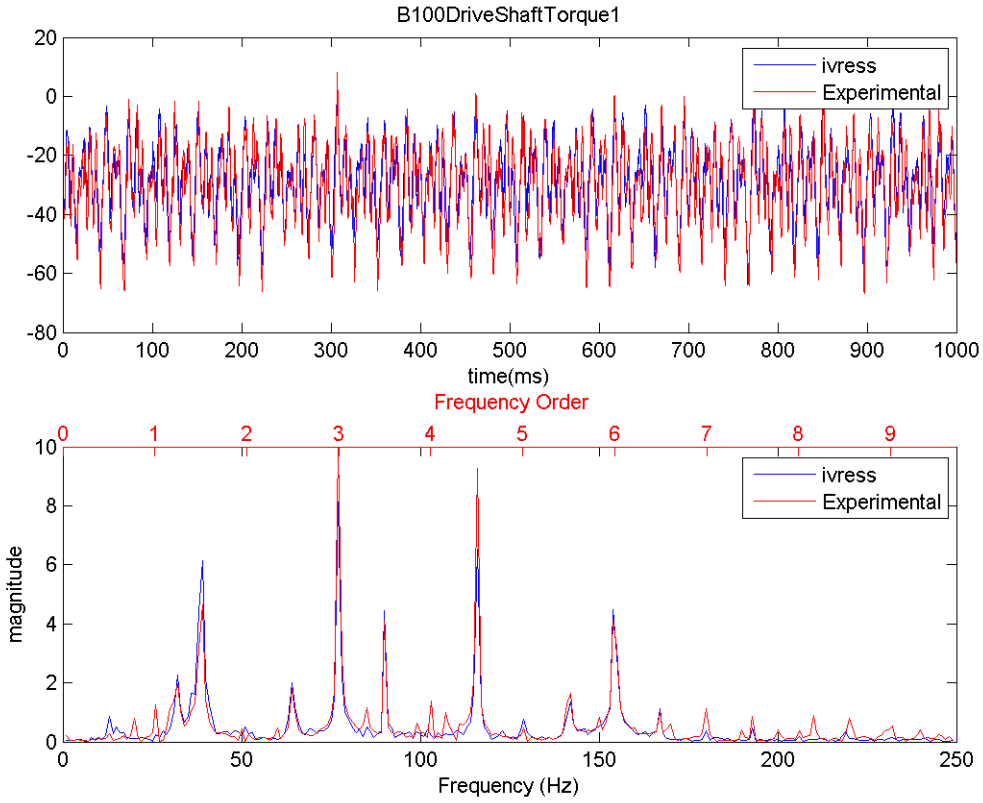

Figure 256 Drive shaft torque in the B100 operation range with turbine shaft torsional damping decreased to 2 $N.m.s/rad$ instead of 4 $N.m.s/rad$

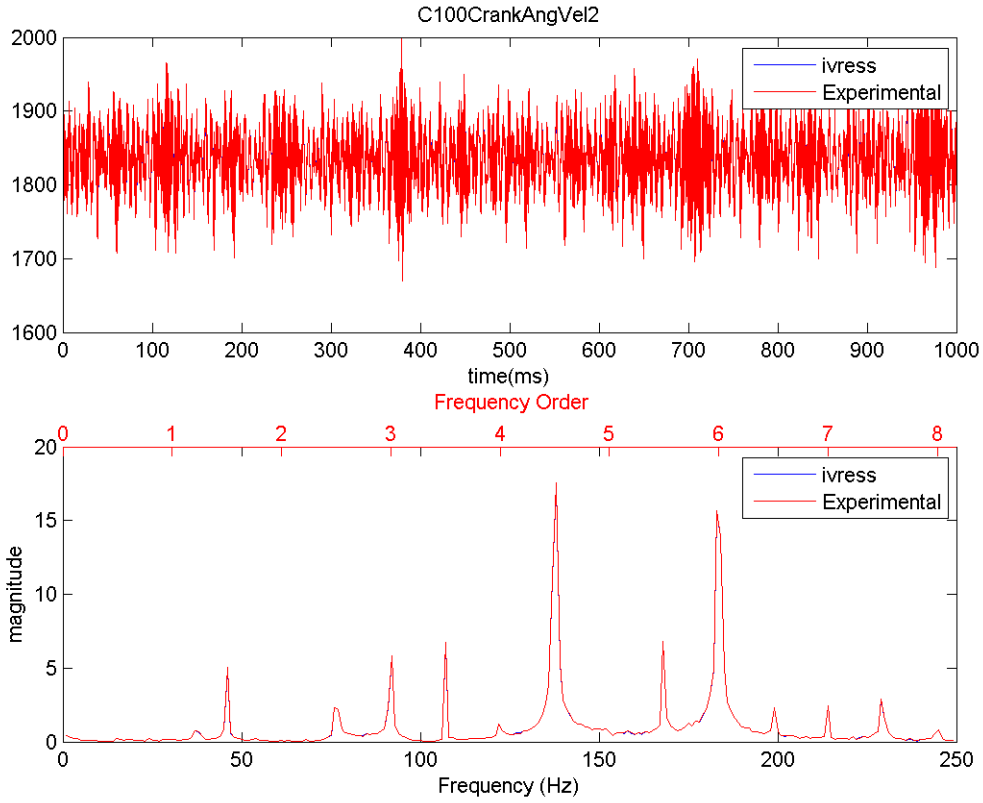

Figure 257 Crankshaft angular velocity in the C100 operation range with turbine shaft torsional damping decreased to 2 $N.m.s/rad$ instead of 4 $N.m.s/rad$

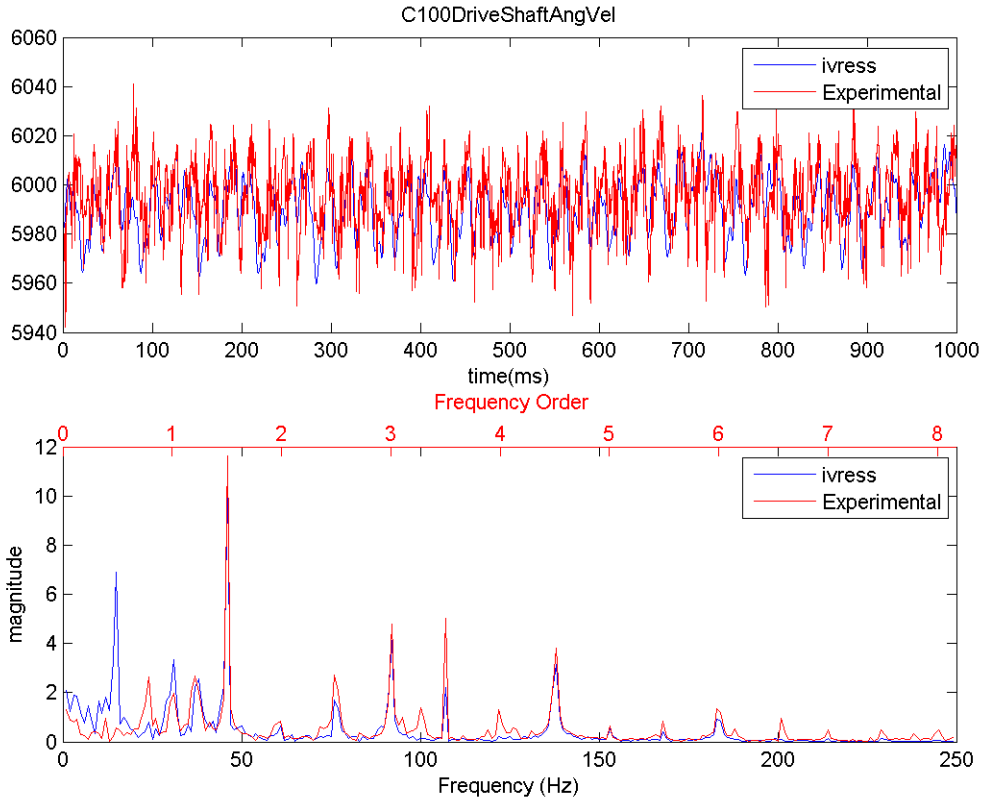

Figure 258 Drive shaft angular velocity in the C100 operation range with turbine shaft torsional damping decreased to 2 $N.m.s/rad$ instead of 4 $N.m.s/rad$

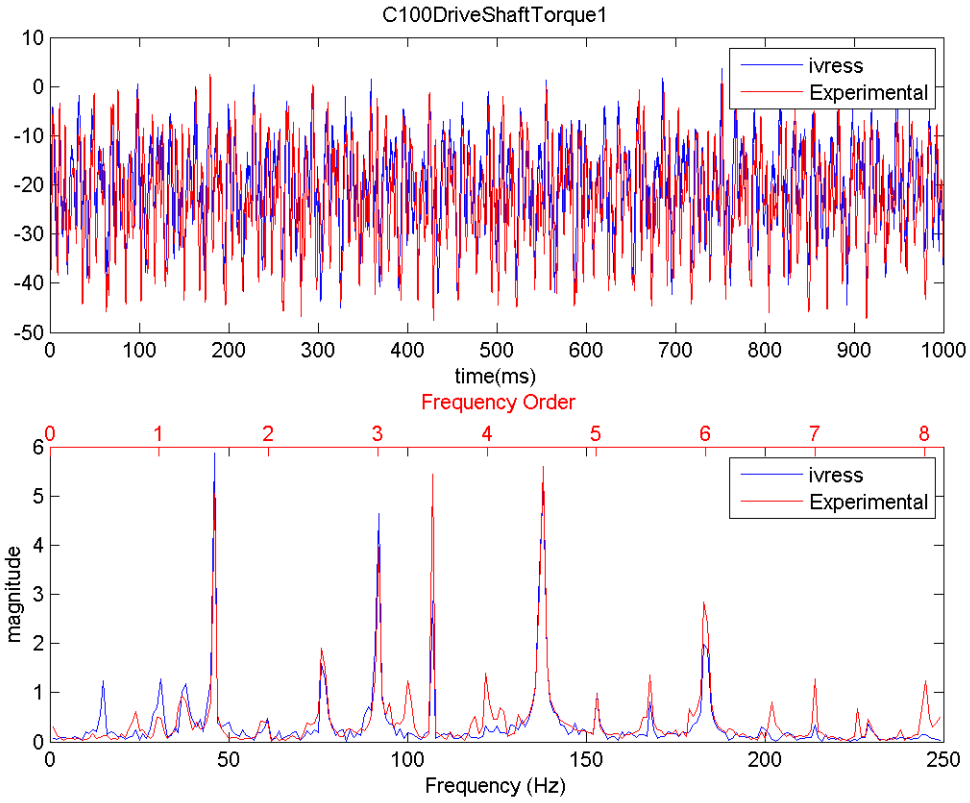

Figure 259 Drive shaft torque in the C100 operation range with turbine shaft torsional damping decreased to 2 $N.m.s/rad$ instead of 4 $N.m.s/rad$

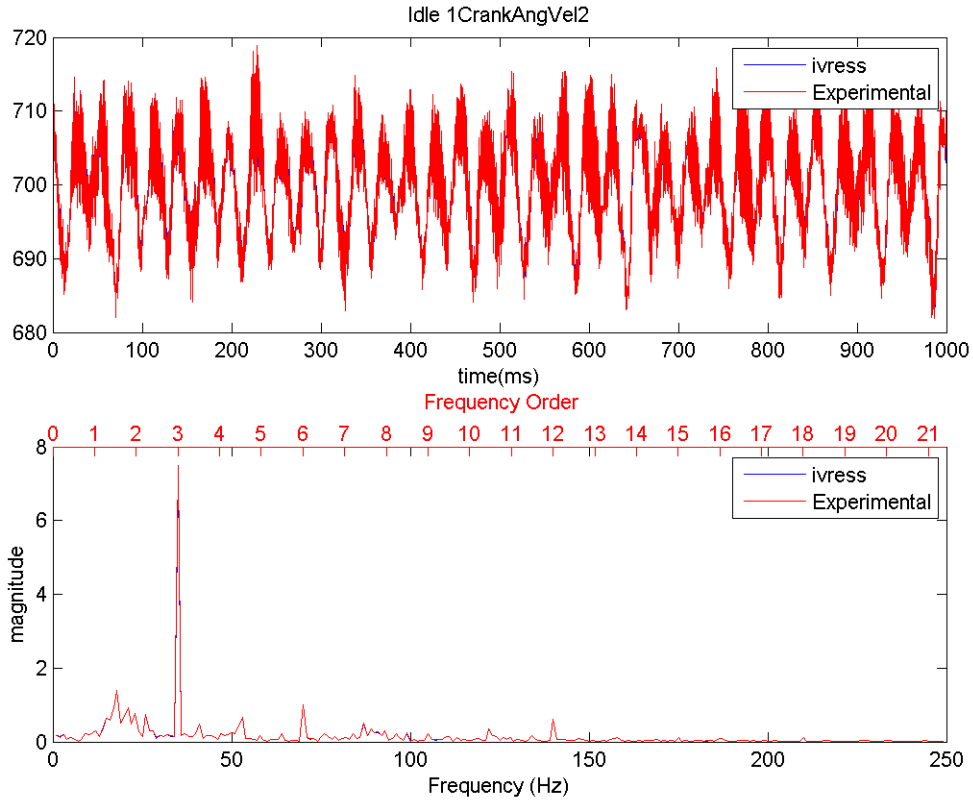

Figure 260 Crankshaft angular velocity in the idle operation range with turbine shaft torsional damping decreased to 2 $N.m.s/rad$ instead of 4 $N.m.s/rad$

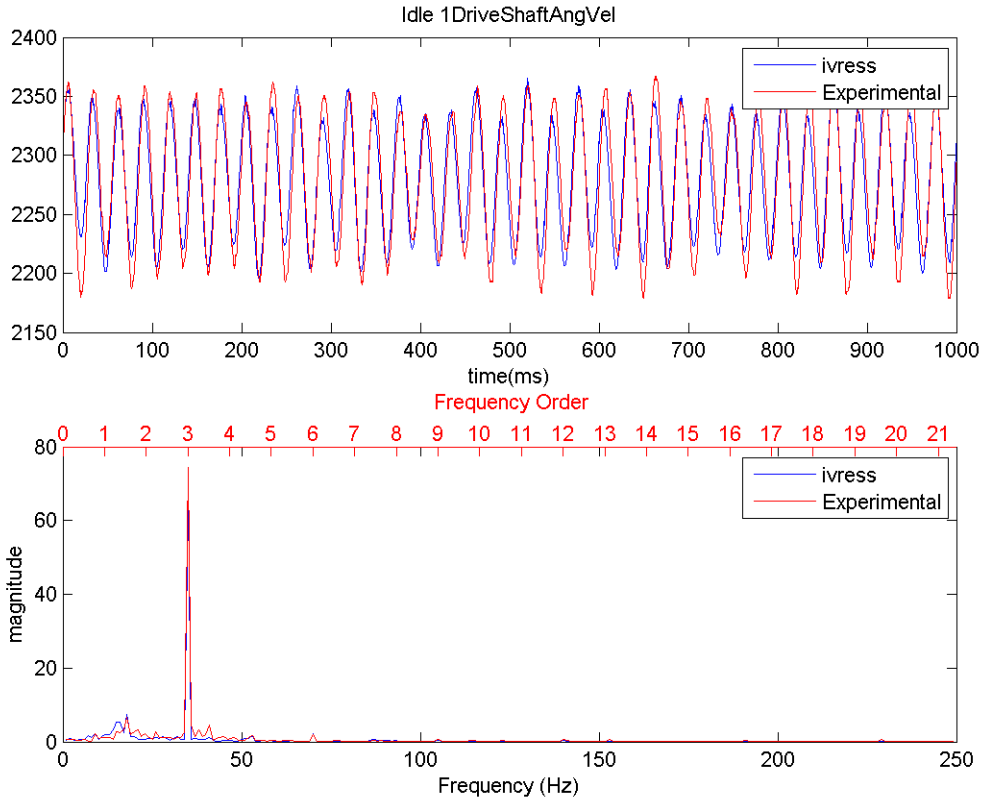

Figure 261 Drive shaft angular velocity in the idle operation range with turbine shaft torsional damping decreased to 2 $N.m.s/rad$ instead of 4 $N.m.s/rad$

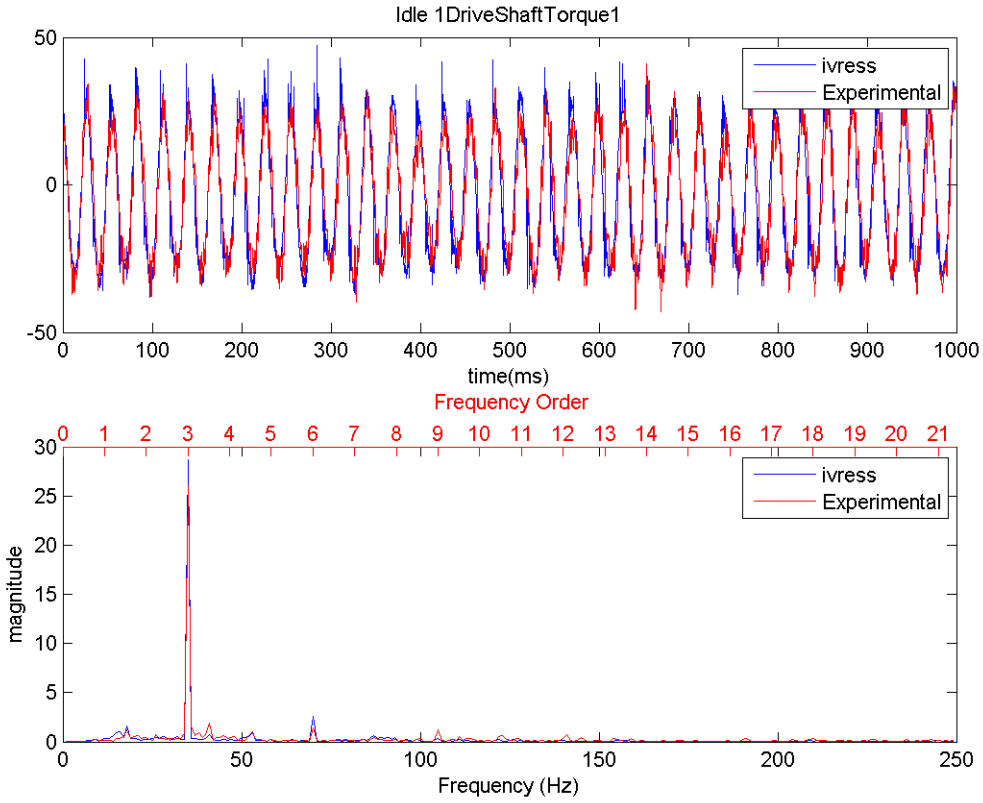

Figure 262 Drive shaft torque in the idle operation range with turbine shaft torsional damping decreased to 2 $N.m.s/rad$ instead of 4 $N.m.s/rad$

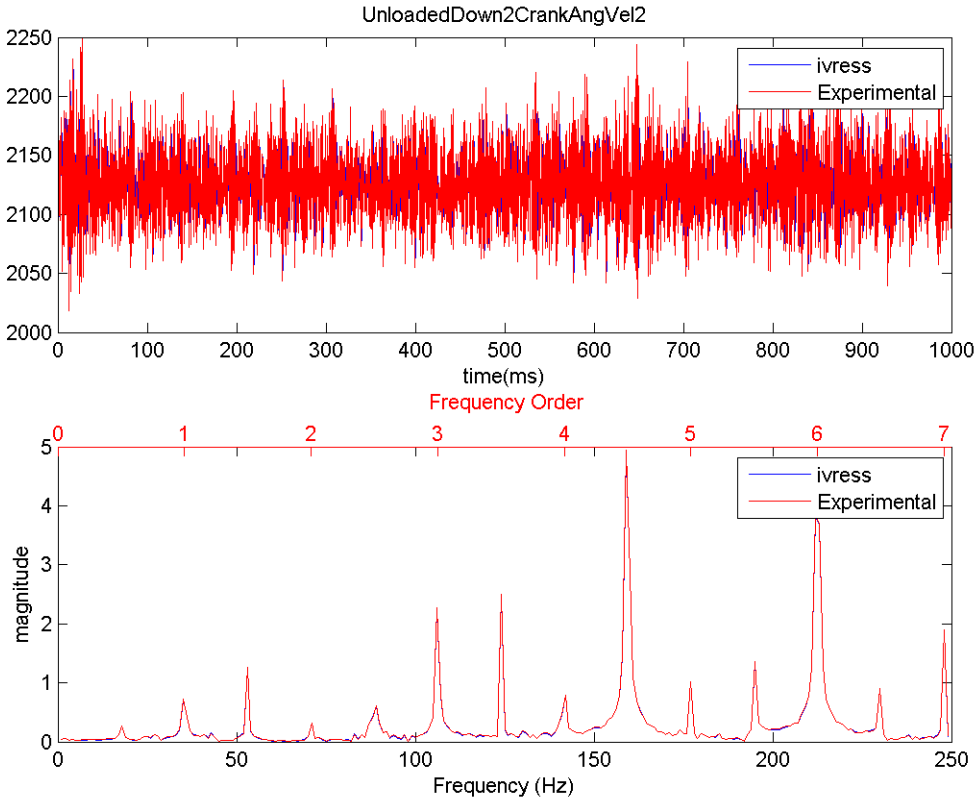

Figure 263 Crankshaft angular velocity in the UnloadedDown operation range with turbine shaft torsional damping decreased to 2 $N.m.s/rad$ instead of 4 $N.m.s/rad$

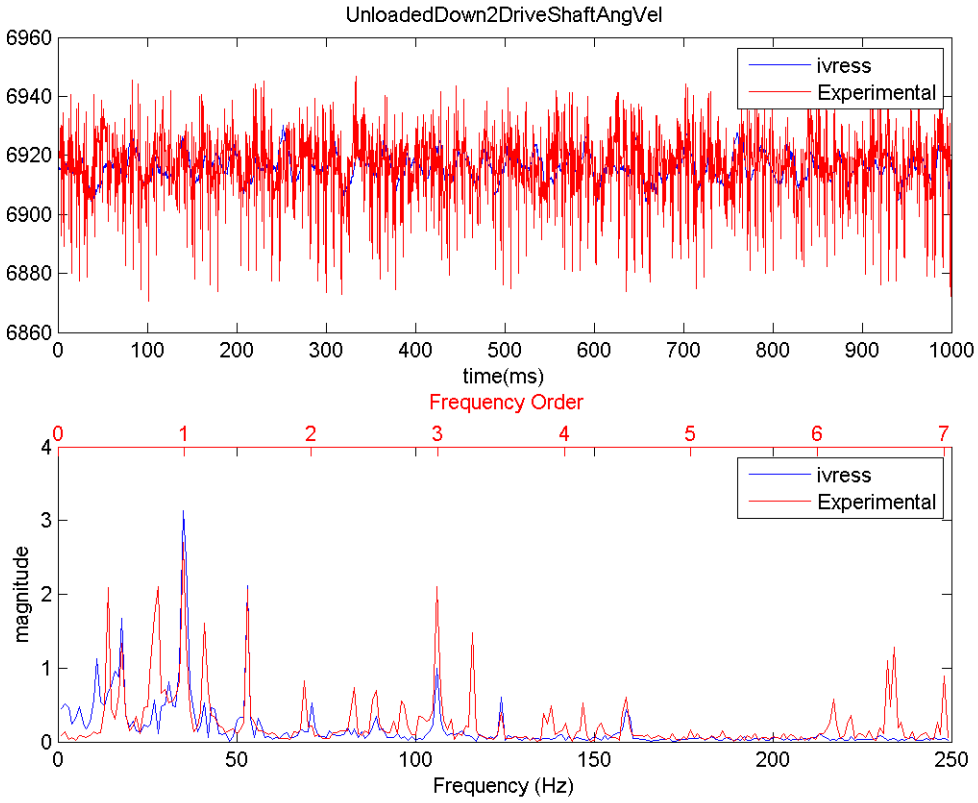

Figure 264 Drive shaft angular velocity in the UnloadedDown operation range with turbine shaft torsional damping decreased to 2 $N.m.s/rad$ instead of 4 $N.m.s/rad$

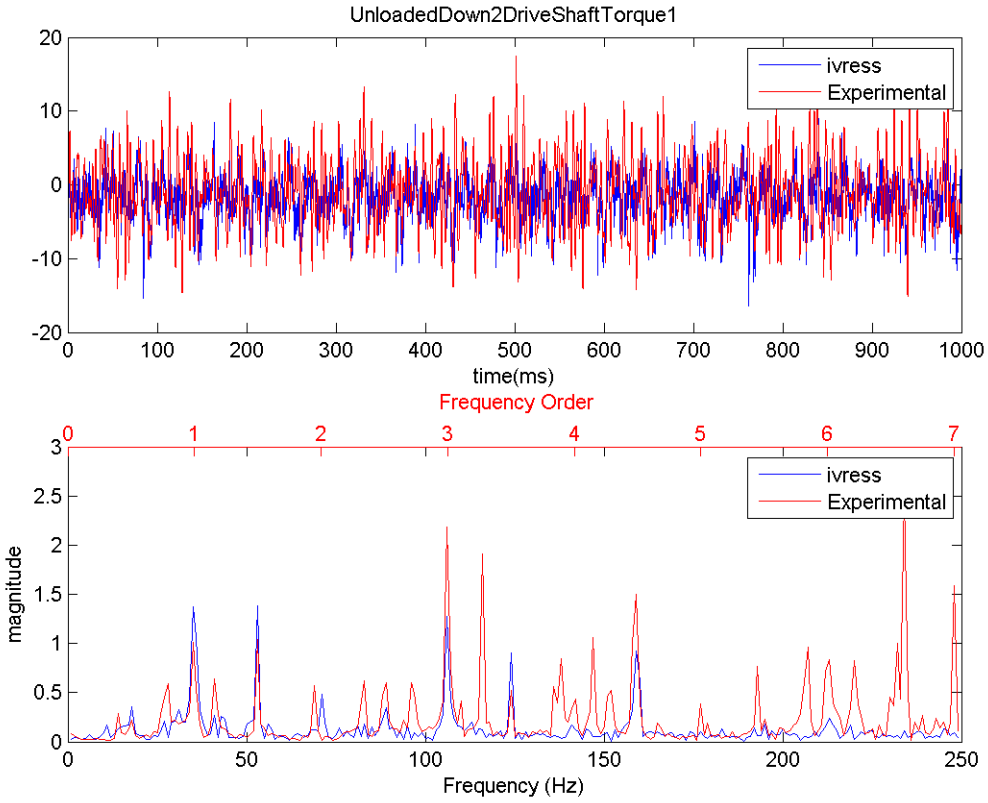

Figure 265 Drive shaft torque in the UnloadedDown operation range with turbine shaft torsional damping decreased to 2 $N.m.s/rad$ instead of 4 $N.m.s/rad$

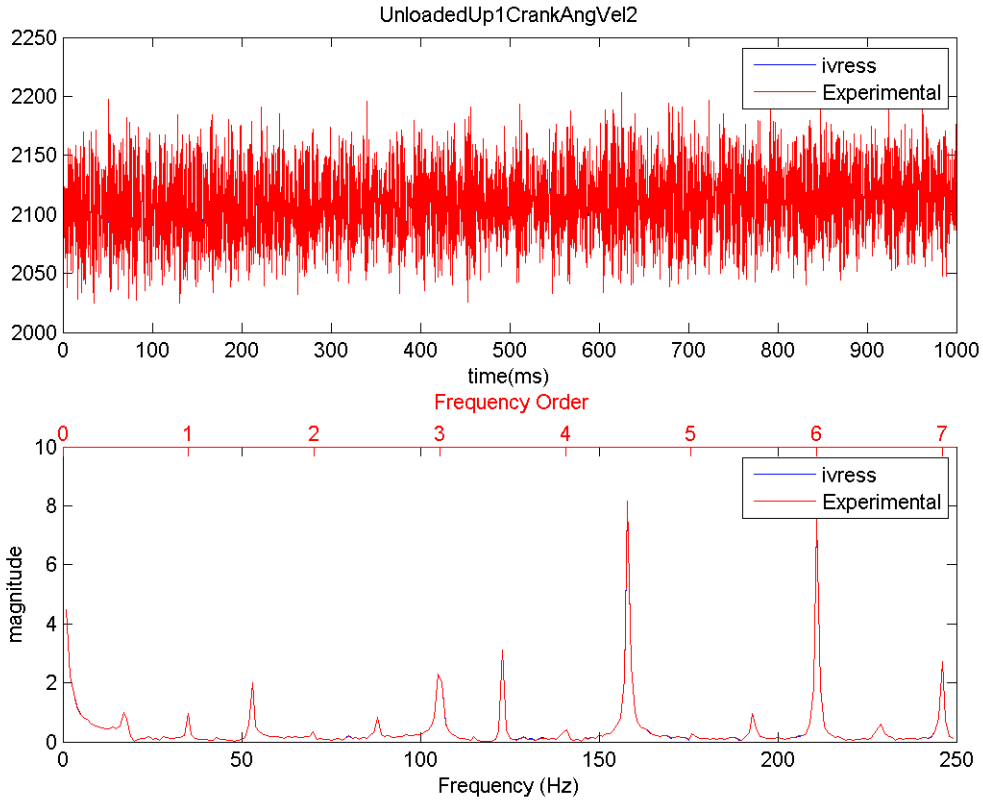

Figure 266 Crankshaft angular velocity in the UnloadedUp operation range with turbine shaft torsional damping decreased to 2 $N.m.s/rad$ instead of 4 $N.m.s/rad$

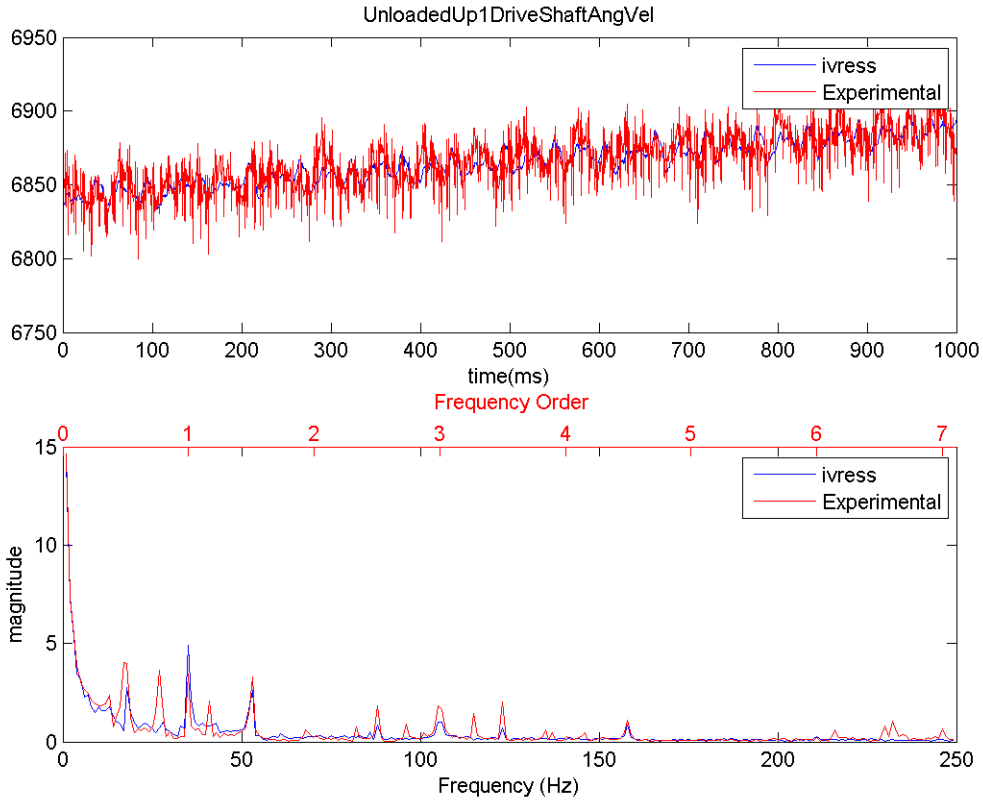

Figure 267 Drive shaft angular velocity in the UnloadedUp operation range with turbine shaft torsional damping decreased to 2 $N.m.s/rad$ instead of 4 $N.m.s/rad$

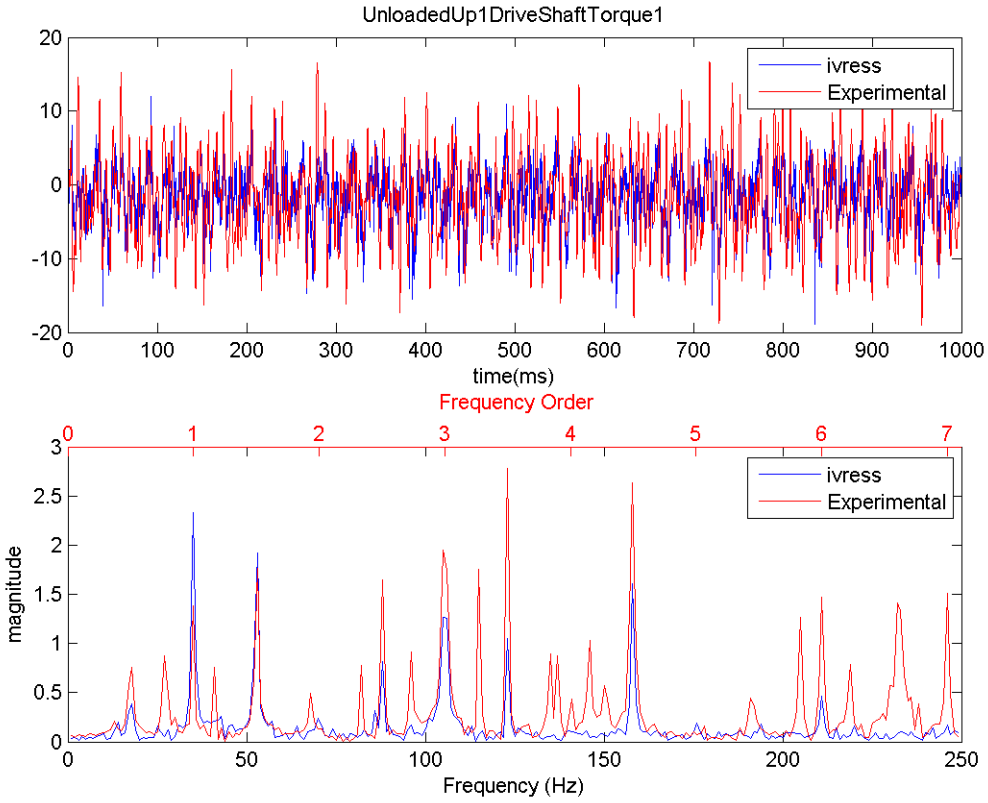

Figure 268 Drive shaft torque in the UnloadedUp operation range with turbine shaft torsional damping decreased to 2 $N.m.s/rad$ instead of 4 $N.m.s/rad$